# FINAL REPORT ON HISTORICAL INFORMATION ON PHYSICAL OCEANOGRAPHIC PROCESSES NEAR LA-2 AND LA-5

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# APPENDIX A

## GENERAL DISUCSSION TOPICS

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## GENERAL DISCUSSION TOPICS

Current Meter Studies and Analysis of
Physical Oceanographic Information for Ocean Dredged Material
Disposal Sites off Los Angeles (LA-2) and San Diego (LA-5)

I. Have you or your institution/agency performed oceanographic studies in the general vicinity of the dredged material sites off Los Angeles and San Diego? If so, what were your findings/conclusions?

II. How would you characterize the regional circulation (surface, subsurface, bottom, and eddies) of this area? What processes dominate? How much do seasonal effects come into play?

III. Discussion of temperature, density, and salinity characteristics of the region.

IV. Are there circulation anomalies in the region due to upwelling or irregular bathymetry?

V. What open literature publications would you recommend as giving good descriptions of the current and hydrographic regimes and the physical processes that result in the observed circulation patterns in the region?

VI. We have interest in characterizing typical current profiles, time and space scales, possible circulation anomalies, dispersal of material disposed in the water column and the likelihood of sediment resuspension. What characteristics of the circulation should we pay particular attention to in analyzing existing and newly collected current meter data?

VII. Are there other experts that you recommend we contact to resolve the issues addressed in topics I - VI?

# 1.0 INTRODUCTION

## 1.1 Background

In May, 1991 a program was initiated by Region IX, Environmental Protection Agency, under Contract No. 68-C8-0062, to conduct current-meter studies and analysis of physical oceanographic information for dredged material disposal sites off Los Angeles, California (LA-2) and San Diego, California (LA-5). The period of performance of this work extends from the date of Work Assignment issuance to September 15, 1992.

On January 11, 1991 EPA Region IX designated the LA-5 ocean dredged material disposal site (56 Federal Register 1112). The LA-2 site was designated on February 19, 1991 (56 Federal Register 6569). The sites became effective for use on February 10, 1991 and March 21, 1991 respectively. The LA-2 and LA-5 sites will be used for the disposal of dredged material that complies with EPA's Ocean Dumping Criteria defined in C.F. R. Parts 220 to 228.

A site management plan was prepared for each disposal site. These plans included placement of current meters designed to measure oceanographic currents and water properties near each site. These data are essential for predicting the movement of disposal plumes and determining the portion of the disposed dredged material that reaches the bottom. For the LA-2 site, a site monitoring report must be presented to the California Coastal Commission within three years. The report will discuss the results of current meter measurements and physical oceanographic information for the San Pedro Shelf, the San Pedro Valley and the San Pedro Channel. The final report will be used to prepare a revised Coastal Consistency Determination (CCD) under section 307(c) of the Coastal Zone Management Act. The California Coastal Commission will review the CCD to determine if the LA-2 site is suitable for long term use.

## 1.2 Specific Tasks

The Work Assignment Request directed that SAIC "contact agencies or experts in physical oceanography who have worked in the vicinity of LA-2 and LA-5 and obtain written reports on physical oceanography data sets from these experts." The information gathered during this program phase will later be used to prepare the final report. All information collected under this historical phase, along with documented copies of the interviews, will be submitted with the final report.

## 1.3 Gathering of Historical Information

To supplement one year of oceanographic instrumentation (July 1991 to July 1992), SAIC contacted experts familiar with physical oceanographic conditions near the two sites in order to obtain relevant historical information. These interviews were used principally to identify literature sources and other field programs as well as gain familiarity with the physical oceanographic processes active in the region. A list and dates of these interviews are provided later in the text.

The structure of the interviews followed a general format that addressed a list of questions developed by the Principal Investigator (Dr. Peter Hamilton), the Program Manager (Dr. Bill Reynolds) and the EPA Work Assignment Manager (Mr. Patrick Cotter). These general questions (Appendix A) were used as an outline for discussion. The most useful product of these interviews was the identification of the body of literature that presently exists regarding the physical oceanographic properties of this region. The interviews were conducted in-person and by telephone.

The key personnel and literature sources became readily apparent almost immediately. Nevertheless, all recommended potential sources, with the exception of those noted in Table 3.1, were contacted, and suggestions of other possible information sources were pursued.

## 1.4 Summary of Interviews

The scientists who have been active in physical oceanographic studies of the Southern California Bight (SCB) were interviewed and questioned about their personal knowledge of studies performed and general information on current regimes that might be expected in the regions of the two disposal sites. The principal sources of the information given in the synopsis of the field studies are identified therein. Table 3-1 gives the relevant information on the interviews. Bibliographic information on supplied reports is given in the references.

## 1.5 Work Remaining

Upon completion of the current meter studies, and data analysis, SAIC will submit a report on the Current Meter Data and Historical Oceanographic Information. At this time, the findings of the historical and field portions will be integrated to allow comparisons of the new field data with the data reported in previous studies. Separate final reports for LA-2 and LA-5 will be submitted.

# 2.0 OVERVIEW OF CIRCULATION PROCESSES IN THE SOUTHERN CALIFORNIA BIGHT (SCB)

## 2.1 Introduction

The LA-2 and LA-5 disposal sites are situated in the SCB on the San Pedro shelf off Los Angeles and off San Diego, respectively. The SCB has complex bathymetry with a strongly curved coastline and is usually defined as the region between Point Conception and San Diego. It is oceanographically distinct from, though linked to, the California Current System, which dominates flows further offshore and to the north.

The SCB topography is characterized by a narrow shelf, of 1 to 10 km width, separated by a steep continental slope from distinct basins having depths of the order of 1000m. There are 14 basins in the SCB, only 7 of which have been the subject of measurement programs. The slope and the shelf are interrupted by steep-sided canyons or shelf valleys such as the La Jolla canyon and the San Pedro shelf valley. The two disposal sites are situated at the edge of the shelf and the top of the slope. Just offshore of the basins are a number of offshore islands including the Channel Islands, Santa Catalina and San Clemente.

Heating over the inland deserts of the SW United States causes a thermally induced atmospheric low-pressure system to form during spring and to intensify during summer. This combines with the persistent Pacific Subtropical high pressure system located off the west coast of the US to drive generally southeastward directed winds in the SCB, which intensify from spring to summer. With cooling in fall, the continental low erodes, resulting in a decrease in magnitude of this seasonal wind pattern. The regional winds in winter are often driven by the Pacific Subtropical high, however, the seasonal presence and strength of the paired low pressure system causes this to become a more vigorous and persistent pattern during late spring, summer and early fall. During winter, the southern California Bight is also affected by winter low pressure (synoptic-scale) systems forming along the frontal system between the higher latitude cool air and the warmer subtropical marine air masses. The Pacific Subtropical high off the coast shifts further southward during winter allowing these low pressure systems to penetrate further southward so the fringes directly affect the local wind field in the SCB.

The atmospheric spring and fall are periods of transition between these two general patterns. The character of the winds in both core patterns (summer and winter) and the transition seasons influence circulation patterns observed on the shelf and adjacent upper slope of the SCB.

The potential influence of the above generalized seasonal wind patterns is moderated by the shape of the coast and the presence of the adjacent channel islands. Lentz (1984) and Hickey (1991) used ship observations to show that the region south of Point Conception is substantially sheltered causing a general reduction in the magnitudes of local winds. These data show a substantial increase in occurrence of lower velocity winds in closer proximity to the coast. The relative occurrence of lower wind speeds (less than 6 m/sec) increases by a factor of three going from the exposed offshore to the coastline along the SCB. These diminished wind magnitudes are evident in both summer and winter seasons.

## 2.2 General Circulation Patterns - Southern California Bight

### 2.2.1 Large Scale Circulation Features

The mean circulation is not well defined, but evidence from the California Cooperative Oceanic Fisheries Investigations (CalCOFI) hydrographic data (Hickey, 1979) and a few longer term current measurements suggest the following pattern. South of Point Conception, the southward flowing California Current branches into two main flows. One branch turns shoreward and then northwestward in a large eddy known as the Southern California Eddy or Southern California Counter Current (Figure 2-1). The poleward flowing part of the Southern California Eddy again splits into two further branches, one inshore and one offshore of the Channel Islands at the Santa Barbara Channel.

The Southern California Eddy, like its parent the California Current, varies seasonally. Maximum poleward (north) flows occur in winter and late summer. In spring, the offshore California Current moves closer to the shore, weakening the counter current and often producing nearshore southward flows in the southern part of the Bight (Lynn and Simpson, 1987).

The poleward surface flow is joined by a subsurface poleward current over the outer shelf and slope, which brings sub-tropical derived water into the SCB. The poleward flow often has a subsurface maximum current

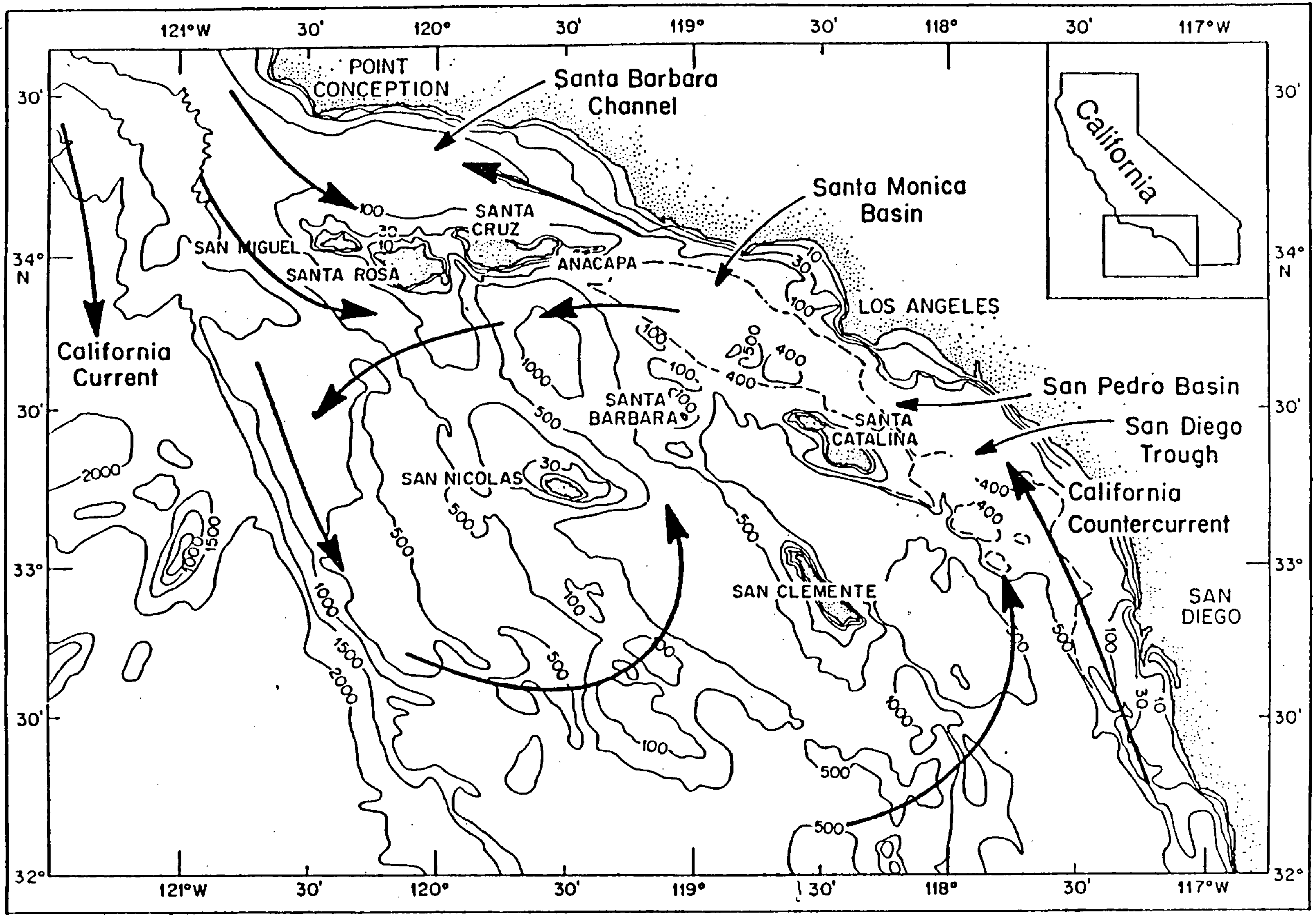


Figure 2-1. Bottom topography and schematic mean circulation patterns in the Southern California Bight

at depths of 50 to 100m and is referred to as the California Undercurrent. In the undercurrent, the water masses are characterized by warm, saline water with low oxygen (Lynn and Simpson, 1990). This is in contrast to surface California Current derived waters which are fresher and cooler (Hickey, 1979; Simpson et al., 1984). In the winter, the undercurrent surfaces in the northern part of the bight producing enhanced poleward flow (Hickey, 1979; Lynn and Simpson, 1987). This northward nearshore surface flow continues north of Point Conception, where it is often referred to as the Davidson Current.

There is known to be interannual variability in the strength of the seasonal flow patterns and water masses in the SCB. The principal cause of this interannual variability is El Niño, which increases the poleward flow of the California Undercurrent bringing warm, salty water into the Bight. El Niño may also change wind patterns and thus affect higher frequency flows. However, there are few long term measurements that adequately address this issue. The main effect of the 1982-1983 El Niño was to increase surface temperatures on the shelf by about 3°C in winter and possibly reduce southward flow in the vicinity of the San Onofre Nuclear Generating Station (Lentz, 1986). It is noted that an El Niño event is occurring during the time of this field program.

### 2.2.2 Wind Forced Circulations on the Shelf

In the summer, the synoptic scale forcing is weak in the SCB with the near-coast winds dominated by diurnal sea breezes. However, on infrequent occasions, tropical storms can travel up from the south, producing strong wind events (Winant, 1980). There is also a synoptic wind pattern called the Catalina Eddy which can last a few days and causes weak upcoast winds and extensive overcast stratus. The winds are caused by a surface low that is generated west of Santa Catalina Island, (Bosart, 1983; Dorman, 1985; Mass, 1989).

During the fall and winter in the southern part of the bight, on the mid- and inner shelf there appears to be a relationship between longshore wind forcing and current fluctuations (Lentz and Winant, 1986). These periods generally last between a few days and a few weeks. The response of the currents on the shelf at Del Mar was found to be a function of both the local wind stress and included a fluctuation caused by coastal trapped continental shelf waves. Because coastal-trapped waves propagate along the isobath with shallow water to their right (i.e. northwards on the west coast), this means that the longshore wind fluctuations of Baja California are responsible for part of the wind-forced fluctuations in the southern part of the bight (Lenz and Winant, 1986). This model of the current response breaks down in summer, probably because of the strong stratification over the shelf and weak winds.

The region north of the Palos Verde (Figure 2-1) shelf has much more complex topography with relatively wide bays separated by very narrow shelves, along with offshore islands. Recent studies in the Santa Monica Bay (Figure 2-1) (Hickey, 1992) have shown that current fluctuations over the inner shelf are only weakly related to the local wind and that the main driving mechanisms were fluctuations over the outer shelf and upper slope involving the cross-shelf velocity components. The outer shelf flow is not strongly related to the local wind but is a combination of responses to eddy flows and long coastal trapped waves. Similarly, current fluctuations in the Santa Barbara Channel (Brink and Muench, 1986) do not have the temporal characteristics of wind-forced flow, and no significant relationship was found between these currents and the wind.

In the winter months, upwelling is persistent north of Point Conception. Upwelling is occasionally observed near the coast caused by the similarity of local winds to the large scale windfield (Halliwell and Allen, 1987). In the summer, coastal upwelling rarely occurs, though upwelled water can be advected into the SCB from the Point Conception region. Upwelling has been observed on the narrow Palos Verdes shelf (Los Angeles County Sanitation District, 1990) and in San Pedro bay (Figure 2-1) (Karl et al., 1981) during spring.

### 2.2.3 Eddies and Mesoscale Circulations

It is well known that the California Current System has a complex eddy field with characteristic scales of 50 to 100 km (Poulain and Niiler, 1989). There is evidence that eddies can occur at preferential locations such as southwest of Point Conception (Simpson et al., 1984; Simpson and Lynn, 1990), perhaps partially trapped by topographic features. Observations show that both anticyclonic (warm) and cyclonic (cold) eddies can occur as dipoles (Simpson and Lynn, 1990) and can have complex vertical structures comprised of the different water masses of the California Current System (Simpson et al., 1984).

Nearer the coastline, a quasi-permanent anticyclonic eddy is observed at the western end of the Santa Barbara Channel (Brink and Muench, 1986; Lagerloef and Bernstein, 1988) and it is possible that other eddies are associated with topographic features such as offshore islands. In a study of the Santa Monica and San Pedro Basins, Hickey (1991) has shown that the lower layer currents are energetic and may be characterized as topographically trapped barotropic waves propagating in anticlockwise direction around the basin. Propagation speeds are about 25 km/day with wave periods of about 10 to 20 days and amplitudes ~4 cm/s. There is some seasonal variability to these deep flows, and they appear to be related to currents in the upper 200m of the water column, which flow over the basins and are part of the Southern California Eddy and California Under Current Circulations.

### 2.2.4 Sediment Transport

There have been few sediment transport studies on the shelves of the SCB. Drake et al., (1985) studied bottom currents and sediment resuspension and transport on the San Pedro shelf during the spring of 1978. They found that bottom current speeds were quite small during this light wind period and were below the threshold for resuspension of the silty and fine sand bottom sediment. Surface wave generated currents, however, were strong enough to produce almost continuous resuspension. At the inner shelf site (23m water depth), this resuspended material was transported offshore by the weak mean currents. At the offshore site (67m water depth), wave-generated currents less frequently produced resuspension events (Drake et al., 1985). Therefore, silts and fine sands are resuspended by the swells and moved offshore to the mid and outer shelf by the mean currents and the occasional upwelling event (Karl et al., 1981). Major sediment transport events which move shelf edge material into the deeper waters of the slope generally occur with winter storms. Karl et al., (1983) remarked that removal of fine grain sediments from the shelf break region was as dependent on the bathymetry and width of the shelf as oceanic processes such as waves and currents. It is therefore difficult to generalize about the shelf-edge transport system.

In studies of the concentration of total suspended particulate matter on the San Pedro shelf, Karl (1980) has shown that modifications to shelf circulation patterns and refraction of surface waves by the San Gabriel (Figure 2-1) submarine canyon create a region where there is preferential sediment transport toward the shelf break. Submarine canyons on the continental slope can also be regions of enhanced upslope currents and thus upwelling and mixing caused by breaking internal waves (Hickey and Baker, 1986; Shepard et al., 1979). Again, the specifics of the interaction of the canyon or shelf valley with the overlying flows of the slope or shelf are functions of the particular topography of a region and it is difficult to generalize.

## 2.3 San Pedro Shelf/Slope - LA-2

### 2.3.1 Hydrography

Hydrographic observations in the vicinity of the LA-2 dump site have been taken to characterize the environment into which sewage effluent is released (Figure 2-2). These outfalls are typically near to shore, (within several kilometers), hence, the associated observations document the inner and mid-portion of the fairly narrow shelf both north of Point Fermin and the wider shelf in San Pedro Bay.

Various measurement programs show a consistent annual cycle of the vertical temperature-dominated density structure. In winter, a well mixed layer extends down to approximately 30 m. Below this,

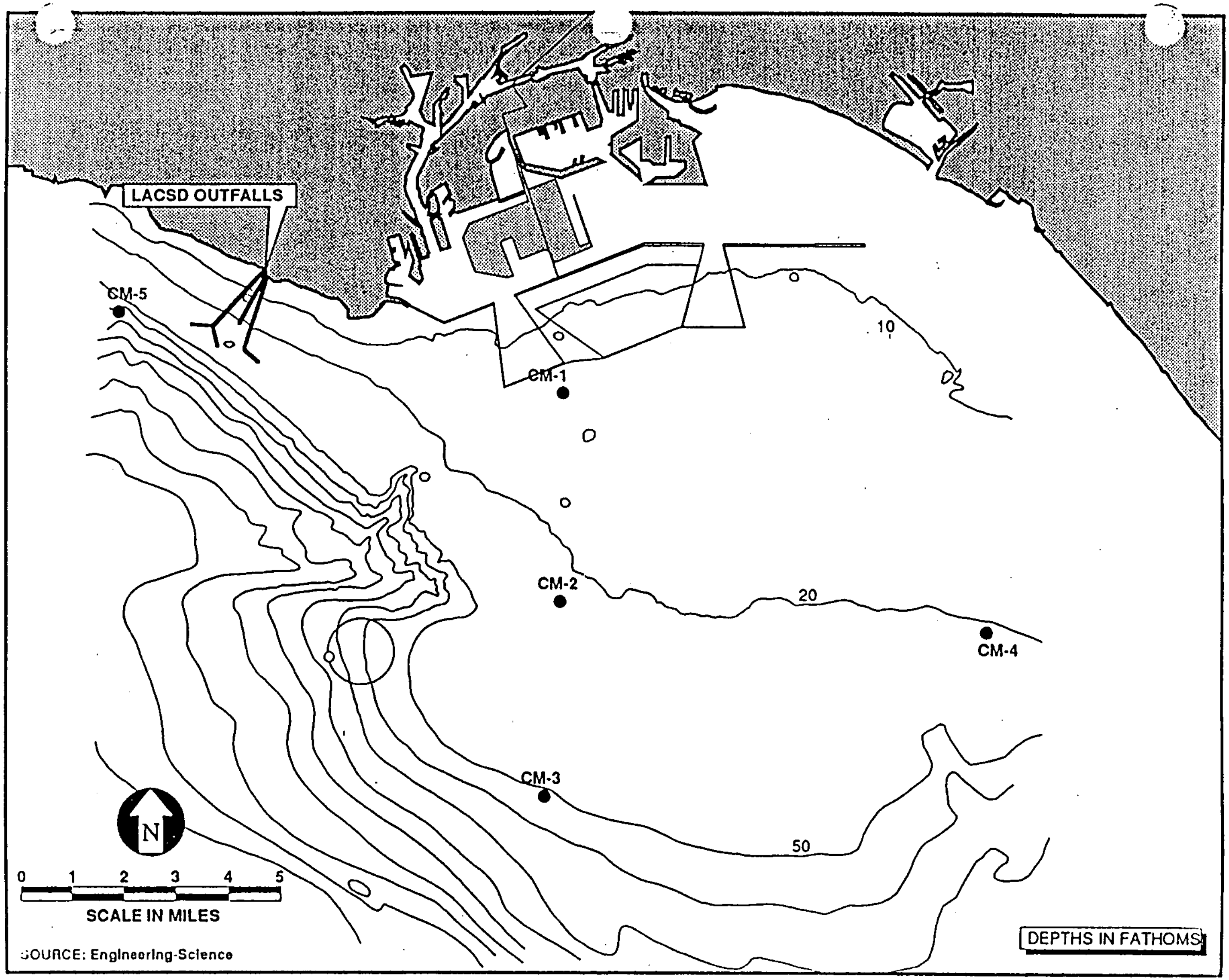


Figure 2-2. A general area map of the San Pedro shelf and upper slope. The Los Angeles County Sewer Districts (LACSD) outfalls off the Palos Verde Peninsula are shown. The small circle southeast of the outfall is the LA-2 site. (Engineering Science, 1991)

temperature decreases from approximately 15°C to about 10°C to 12°C at 100 m. Several sets of observations taken in the late 1980's suggest that these deeper temperatures remain relatively unchanged throughout the year. With winter cooling, the surface mixed layer continues to cool until spring (approximately March/April) when surface heating establishes a shallow, warm, near surface layer. With the transition to summer the surface layer continues to warm, creating a stable temperature dominated density structure that inhibits vertical mixing from the less frequent storm events. This stable structure persists until cooler temperatures and shorter days tend to diminish the surface water temperatures (e.g. September, October and November). With the return of periodic, more vigorous winter storms and reduced vertical stability, a mixed layer is established and expands vertically to complete the annual cycle. The strong, temperature-dominated stratification in summer helps uncouple the circulation above and below the seasonal thermocline and hence isolate the deeper shelf waters from direct effects of wind forcing as well as inhibit upwelling. As a range, surface waters in the San Pedro region rise to approximately 21.5°C in summer with 10°C - 12°C water common near the bottom at mid-shelf locations during most of the year. In winter, surface waters can be cooled and mixed so surface temperatures were reduced as low as 10°C.

At depth, salinity may help produce a more rich and varied spatial density field. However, most of the available observations were made to document effluent from operational outfalls, and this freshwater source may have had an effect on the observed fields. Washburn (1991) showed that for an extensive data set taken on the shelf off the Palos Verde Peninsula, the observed temperature variation was due in large part to natural (oceanic/meteorological) influences while observed salinity variability was more influenced by the discharge of treated freshwater. Some data suggests that higher density (cooler and more saline) waters intrude onto the shelf in spring and can actually reach the surface during local upwelling events, which occur with the upwelling favorable southeastward directed winds prior to the stable stratification of summer. (Palos Verdes County Sanitation Annual Report, 1990).

A 25-year time series of temperature measured near the LACSD outfall on the Palos Verde shelf provides a valuable source of data for putting the San Pedro shelf temperature patterns in an historical setting. In that project, temperature profiles were measured approximately monthly in a water depth of 60 m at a set of 10 standard depths, four of which were in the upper 10 m of the water column. These data (Figure 2-3), which are presented as temperature anomalies (the mean has been removed), have been filtered to suppress seasonal variability. As a result, the interannual pattern is most apparent. From these time series, vertical patterns can be identified as well as scales of very low frequency variability.

From 1965-1980, a visibly obvious oscillation persisted with a period of greater than a year but generally less than 2 years. Two times (1973 and 1977-78) during these 15 years, mean or slightly warmer conditions

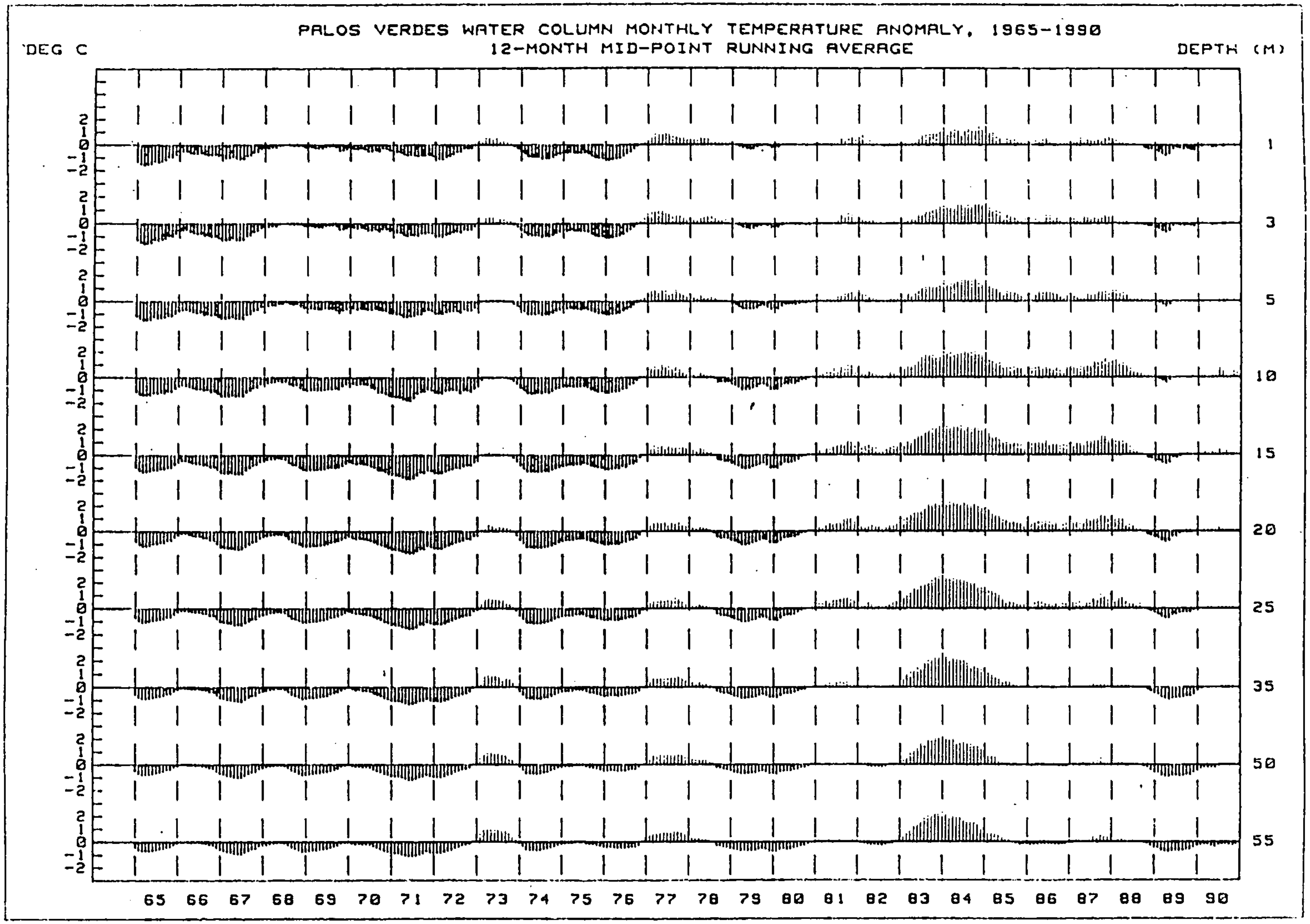


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Figure 2-3. Time series of temperature anomalies from the LACSD area. Depths are shown to the right. (LACSD, 1991) occurred. During the rest of the time, temperatures were below the mean. In 1980, a dramatic change seems to have occurred. Almost all anomalies at all depths remained at or above the long-term mean at each depth. Temperatures as much as 3°C above the depth mean were measured. In particular, the interval between 1983 and 1986 was consistently warmer at all depths with the effects in the lower half of the water column slightly more pronounced. Other observations from the area indicate that these deeper shelf waters do not have a strong seasonal temperature signal, which suggests that some substantive and persistent change in circulation patterns brought warmer waters to the site. With the exception of approximately 1989 through 1990, water temperatures at the measurement site have remained at or above the mean. In 1990, the pattern seems to be warming; however, this pattern is weak and not consistent at all depths.

### 2.3.2 Currents, Circulation and Transport: LA-2

Previous material (Section 2.2) provides a good general overview of regional circulation patterns in the Southern California Bight. Superimposed on these are site specific or local currents which display additional variability.

On the San Pedro shelf and slope, tides are mixed with significant and comparable diurnal and semidiurnal components (Figure 2-4). As a first order, tides can be assumed to provide no net transport; however, this assumption may not be appropriate if considering transport of material settling through the water column. On the shelf near bottom tidal currents are sufficiently strong to transport the fine fraction (silts and clays) of bottom sediments.

Four years of current measurements at the Orange County outfall located at the southern end of San Pedro Bay (Figure 2-5), provide basis for a generalized seasonal pattern of alongshore currents (CSDOC, 1989). In summer, the strong, stable near-surface density gradient creates a two-layered system. The near-surface (upper 20m or so) currents are toward the equator (downcoast) while deeper currents are often directed upcoast. With surface cooling and mixing in fall, the stable stratification erodes such that currents in this upper layer reverse and are directed upcoast, as are the deeper currents. The seasonal change in upper layer direction is in keeping with the seasonal cycle in the strength of downcoast directed winds. This upper layer pattern contains interannual variability in the strength of the equatorward flow and the strength and timing of reversals. Lower layer transport remains consistently directed poleward (upcoast); however, periodic, relatively short reversals to downcoast flow lasting a week or less were seen (CSDOC, 1989).

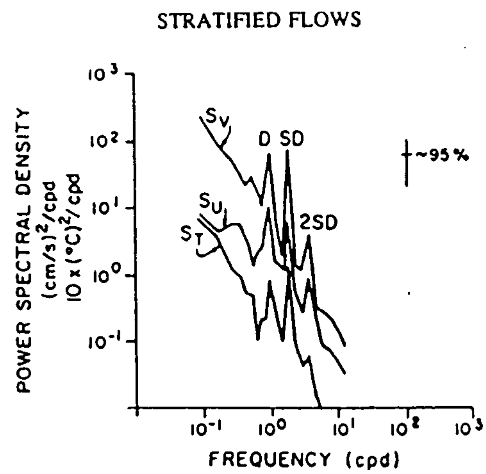



Figure 2-4. Spectra of currents showing diurnal (D) and semidiurnal (SD) peaks for alongshelf (v) and cross shelf (u) components. (Washburn, 1991)

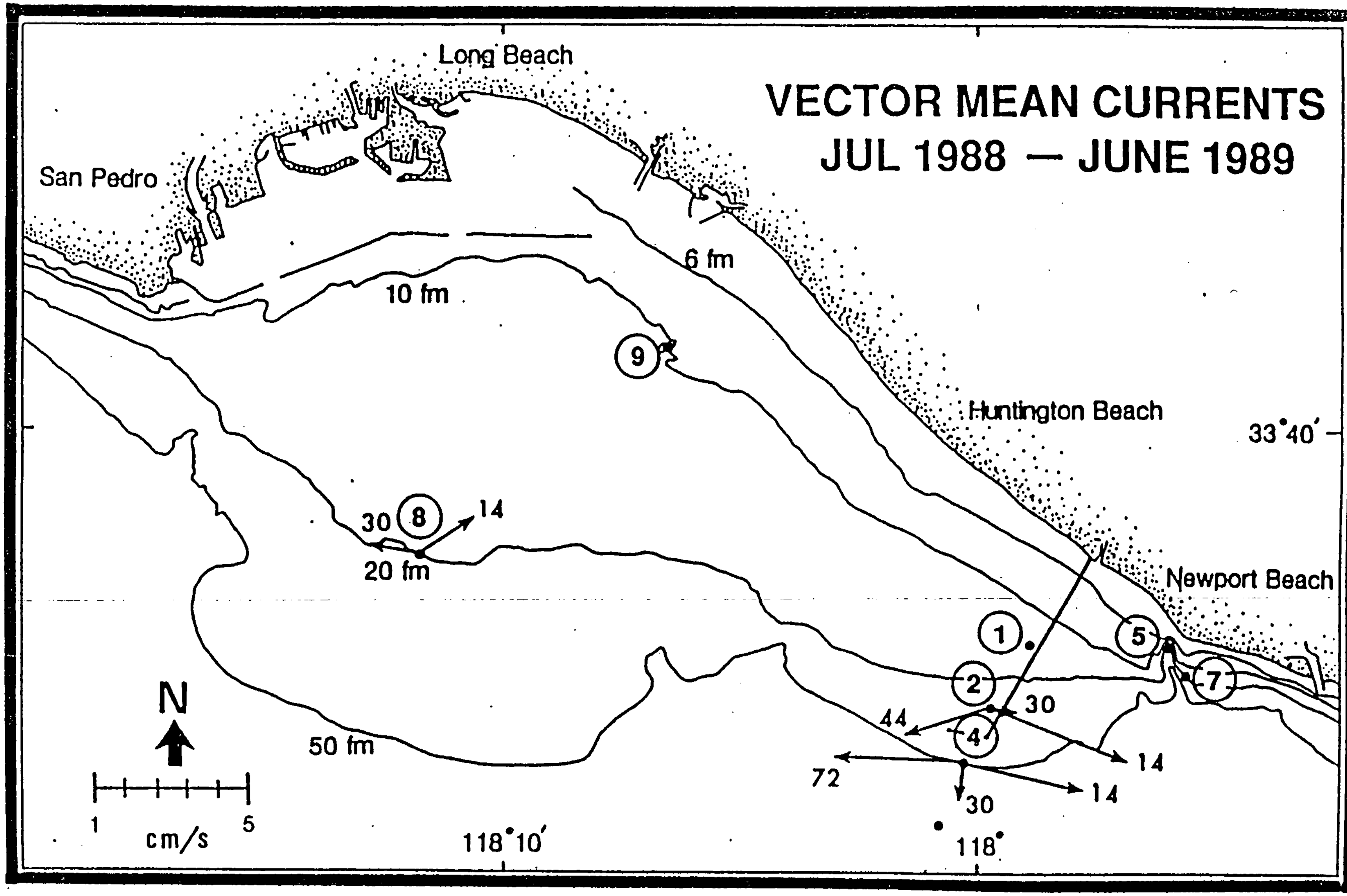



Figure 2-5. Current measurement locations are shown by circled numbers. (CSDOC, 1986)

While some general year-to-year patterns of local currents (transport) have been identified, a consistent pattern which would help explain the observed longer term temperature time series (Figure 2-3) is not apparent. Although warmer conditions have persisted since 1980-81, 1986-89 may be transition years in the overall circulation pattern or in the water type being advected into the region from the south.

Near-bottom, low-pass filtered current measurements (Figure 2-6), on the wider portions of the shelf in San Pedro Bay just south of the Palos Verde Peninsula, showed that mid-shelf currents were similar to but generally less energetic than those measured at the shelf break (Drake, et al., 1985). Currents measured on the mid- and outer shelf showed a consistent southward (downcoast directed) flow with a substantial offshore component. This occurred while the light, daily average winds (approximately 3 m/sec) were directed upcoast. These same data showed that in the absence of significant wind stress events, bottom currents were dominated by tidal currents that were strong enough to transport the finest sediment fractions and the bottom nepheloid layer. The coarser bottom material was only responsive to the larger, longer period swell. Karl et al., (1983) suggests that the upcoast movement of sediments on the San Pedro shelf is blocked by the Palos Verde Peninsula to the north or the Newport Canyon to the south. He also noted that near bottom currents responded rapidly to local changes in wind direction. During that 40-day, fair weather study period, the near bottom currents tended to carry material offshore.

Over a 10-day study in August 1986, currents and temperature were measured on the 200 foot (61 m) isobath as part of a study of waste water plume dynamics off the Palos Verde Penn. This limited data set splits such that during the first six days, variable currents at all depths were directed primarily downcoast (Figure 2-7). During the last four days, a vigorous upcoast transport event occurred at all depths. While currents were directed downcoast, thermal stratification increased slightly and was eliminated during the upcoast transport phase. Note that all of these observations were made near or below the thermocline depth expected in this region in August.

San Pedro shelf currents were measured (Engineering Science, 1991) during three typical oceanographic seasons: winter (well mixed), spring (upwelling frequent) and summer (stably stratified). Observations made at five locations across and along the shelf (Figure 2-5) were at depths of 10 m or 26 m regardless of total water depth; thus, measurements were at or above the expected summer thermocline depth. In summary, the following pattern of currents was observed:

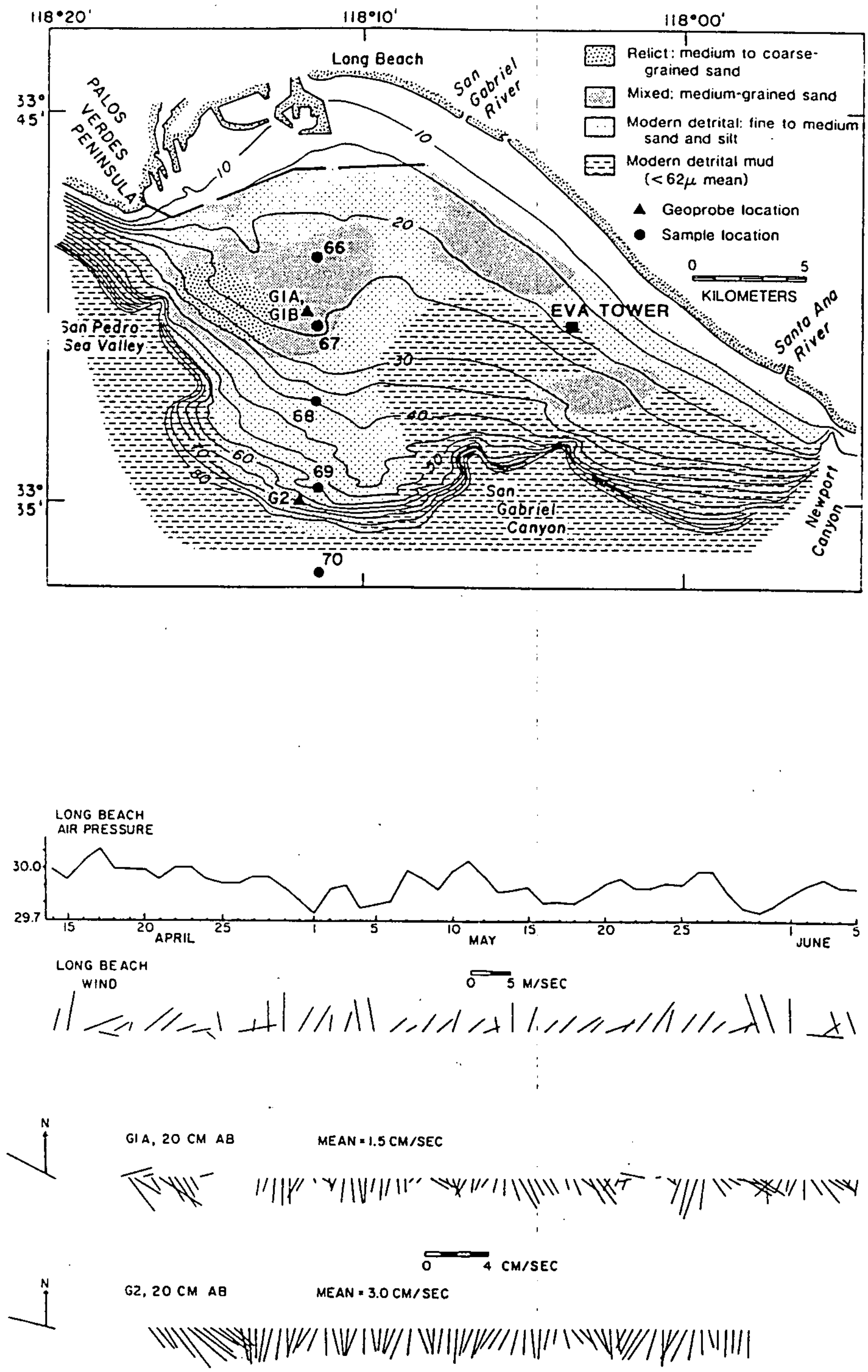



Figure 2-6. On the upper drawing the triangle marks the near bottom (GEOPROBE) measurement sites. The low pass filtered wind and current data is shown below. (Drake et al., 1985)

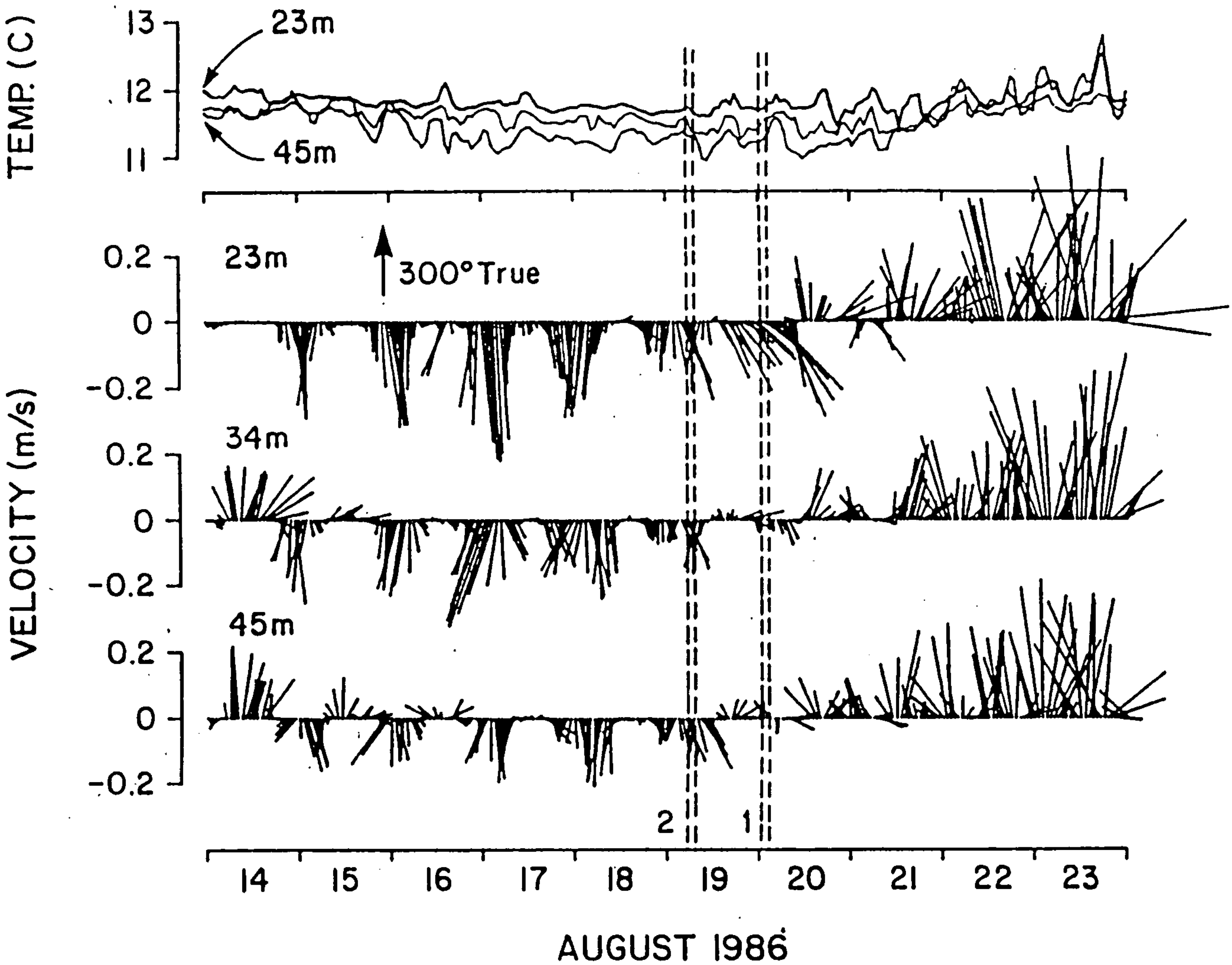



Figure 2-7. Currents and temperatures measured over 10 days in August close to the Palos Verde outfall site. (Washburn, et al. 1992)

- Mean currents were directed downcoast in winter and spring and upcoast in summer, except off the Palos Verde Penninsula, where currents were always directed upcoast. While this seasonal pattern existed, higher frequency (but subtidal) current variability was clearly present and an important component of the current field.

- Within seasons, mean currents were weak as compared to the subseasonal scales of variability.

Using EOF analysis, two primary modes were identified, which contributed 68-91% of observed current variance (depending on the season). Fairly consistently over the three seasons sampled, the first mode represented along-isobath flow. Mode two suggested the presence of a cyclonic (counterclockwise) rotating circulation pattern. It can not be said that this truly reflects an eddy; however, it does suggest that currents on the inner and outer portions of San Pedro Bay may contain currents having an opposite sense of direction.

As discussed in the previous overview material, the California Current and associated southern California eddy have an influence on surface circulation over the San Pedro slope and adjacent basin. The upcoast (poleward) arm of this mean gyre combines with the California undercurrent to dominate circulation patterns in the upper water column (depths less than 500 m) of the marginal basins. The undercurrent, which brings warmer saltier water northward, is strongest between 100-300 m. These general upcoast flows have a seasonal cycle such that the maximum occurs in summer and fall when the California Current and Undercurrent are strongest and in winter when the Undercurrent rises and reaches the surface somewhere in the general Santa Monica-San Pedro basin complex. Maximum upcoast transport over the slope is in spring (Hickey, 1979).

Relatively few subsurface current measurements have been made offshore of the San Pedro shelf. The LA-2 site is located just off the shelf on the upper slope and is positioned on the upper, southern edge of the San Pedro Canyon. To date, no data in this canyon has been identified so the potential for either up or down canyon flow and any disruption of general along-isobath flows can not be evaluated. Observations being taken in the present program will provide a data base for evaluating potential canyon effects on circulation.

A comprehensive current data set taken by Hickey (1991) in fall/winter 1985 and summer/fall 1986 on the Santa Monica shelf and slope just to the north of the LA-2 site (Figure 2-8) showed the following important current patterns:

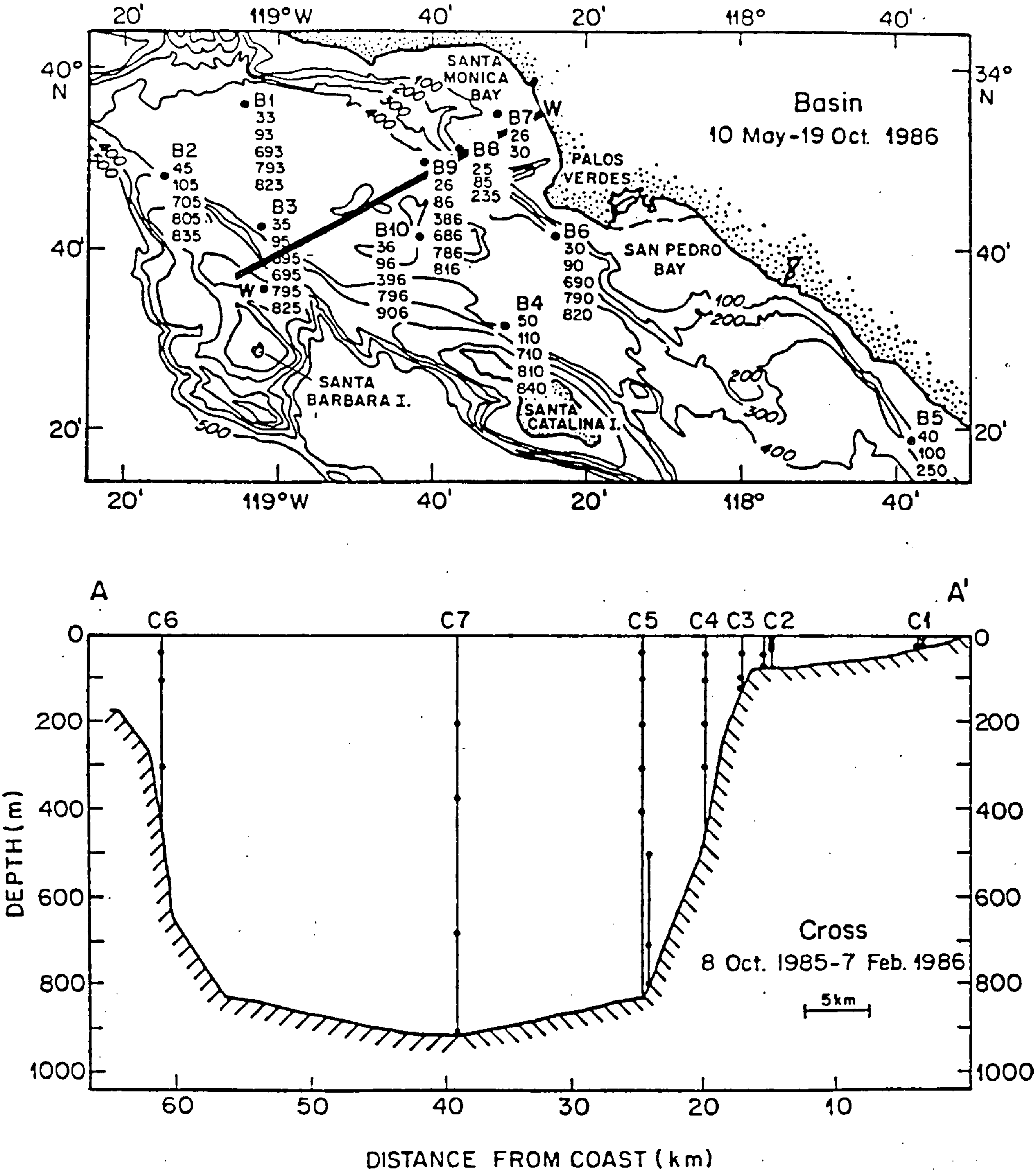



Figure 2-8. Mooring locations for Cross and Basin studies. The mooring transect shown in the lower drawing was approximately across the middle of the Santa Monica shelf, slope and basin. (Hickey, 1992)

- Outer shelf currents at subtidal frequencies (20-30 days) are coherent with those over the slope (Figure 2-9),

- Slope currents are quite coherent over an extended vertical range (down to approximately 400-500 m) (Figure 2-10),

- Inner shelf currents have a substantial subtidal component of variability; however, they are not very coherent with outer shelf currents (Figure 2-11), often being directed downcoast while outer shelf current are upcoast. On the shelf, shorter scale motions (5-10 day) are more evident and may be wind related.

- At subtidal frequencies, spatial coherence along the San Pedro Basin shoreward slope does not appear to be strong, although mesoscale features are clearly present (Figure 2-12).

Figures 2-8 through 2-12 show a strong along-isobath, generally upcoast flow. On several occasions, reversals or strong cross-isobath flow events occurred at both stations B6 and B9; however, during these events the current patterns were different at the two locations. At these mid slope locations (B6 and B9) flows remained strongly directed upcoast at 30m below the surface. Similar but more vigorous (stronger) currents occurred at 100 m (Figures 2-11, 12, 13).

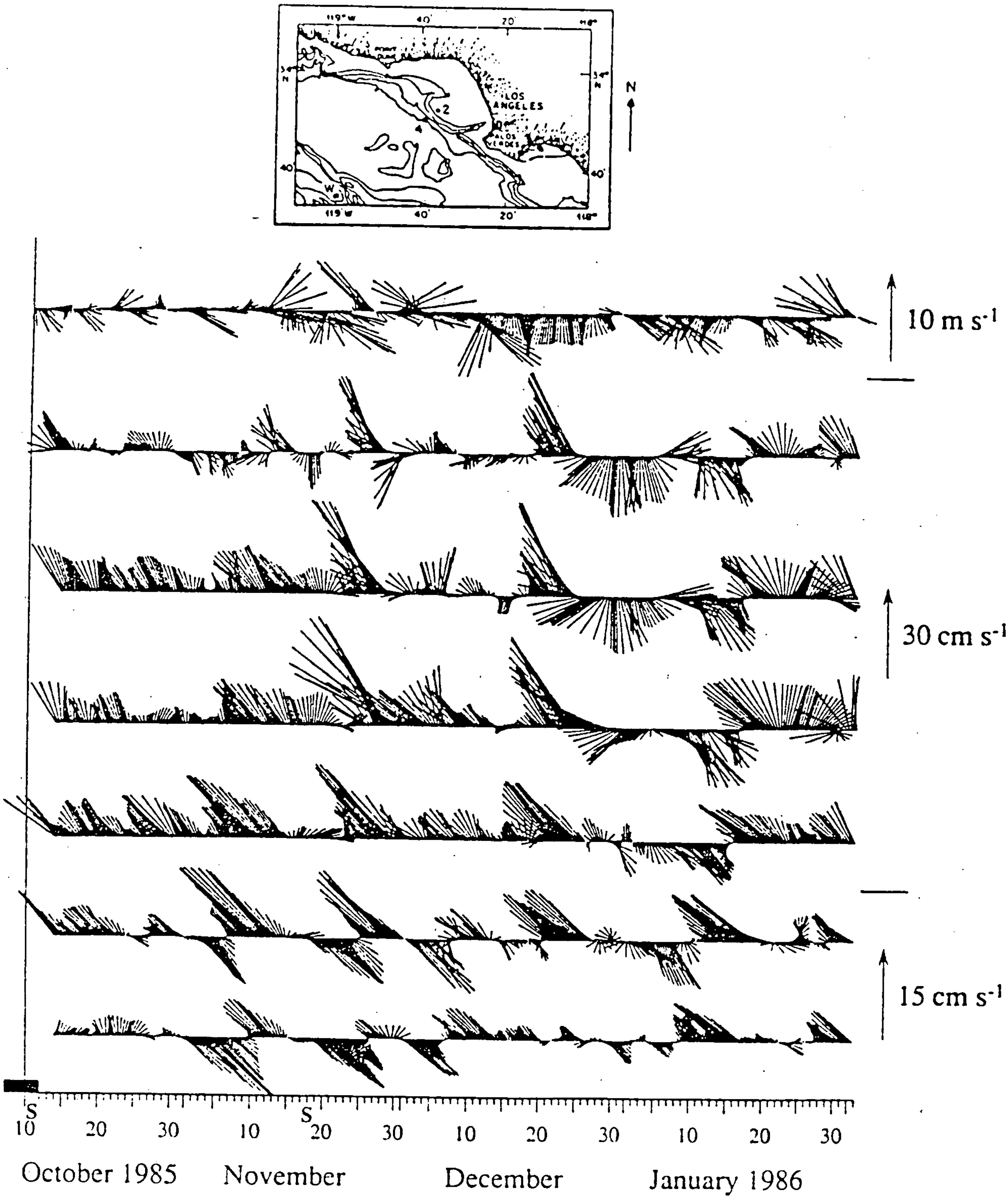



Figure 2-9. Low pass filtered current vectors at the indicated sites and depths as measured during Cross (Hickey, 1992)

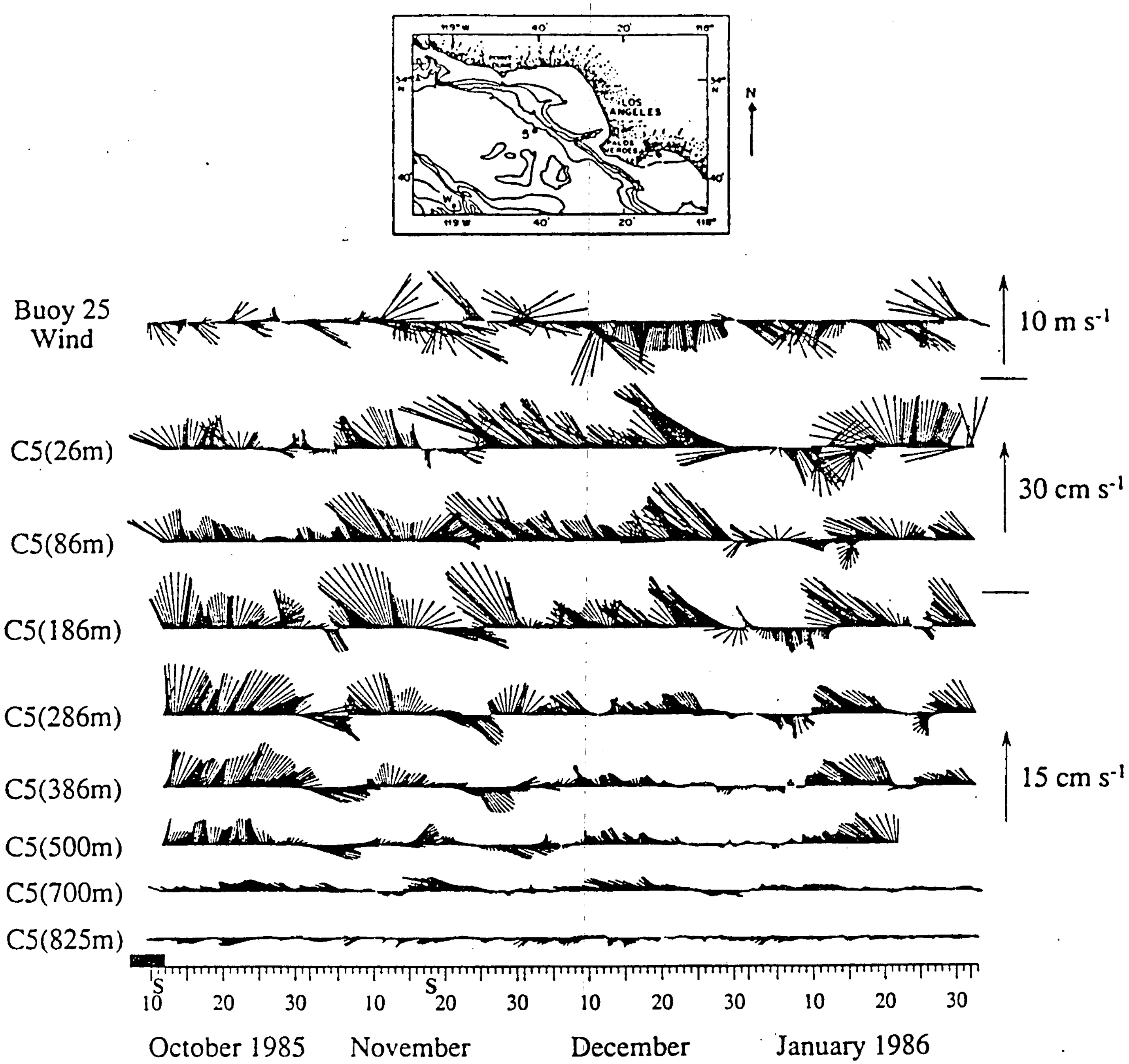



Figure 2-10. Low pass filtered current vectors at the indicated sites and depths as measured during Cross (Hickey, 1992)

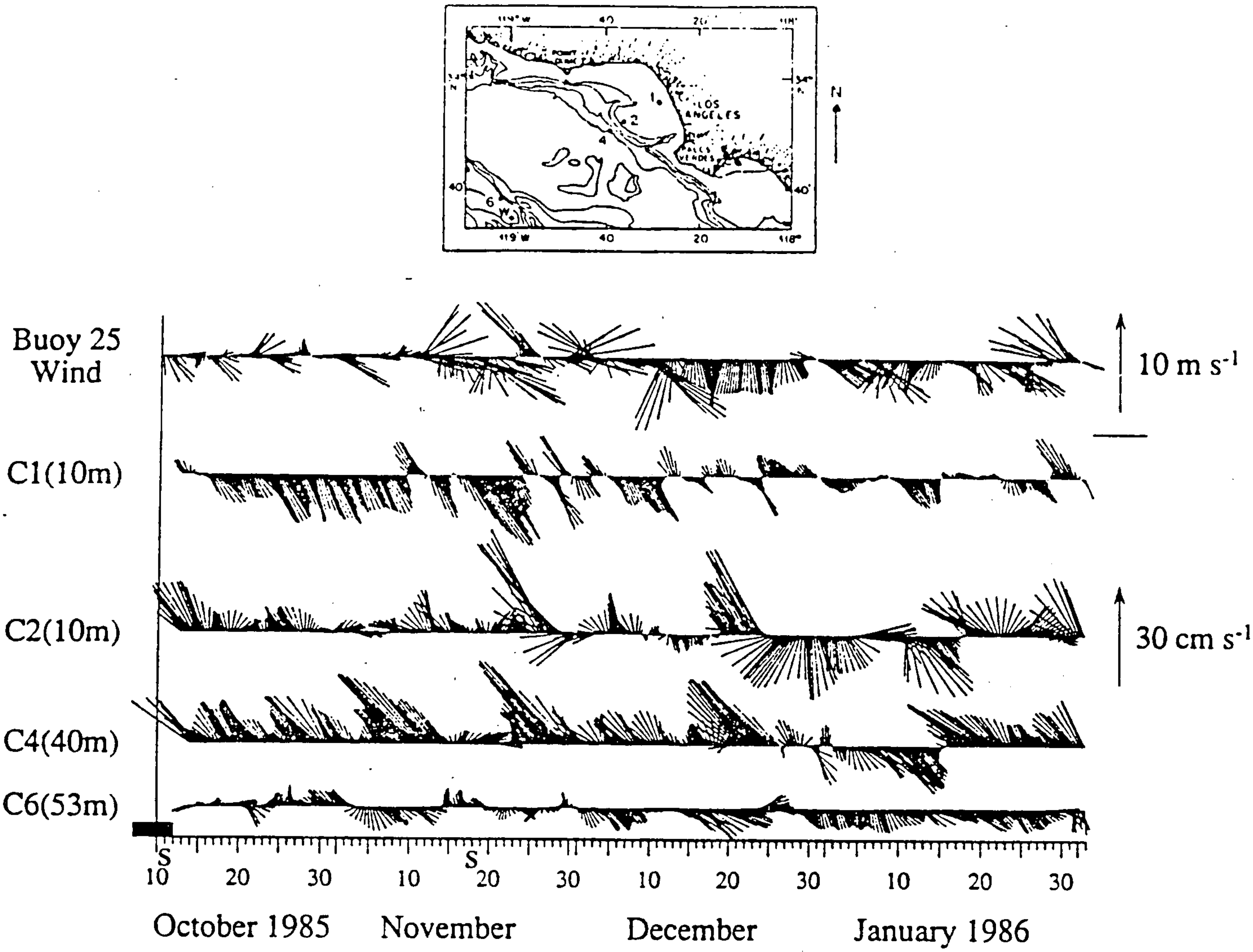



Figure 2-11. Low pass filtered current vectors at the indicated sites and depths as measured during Cross (Hickey, 1992)

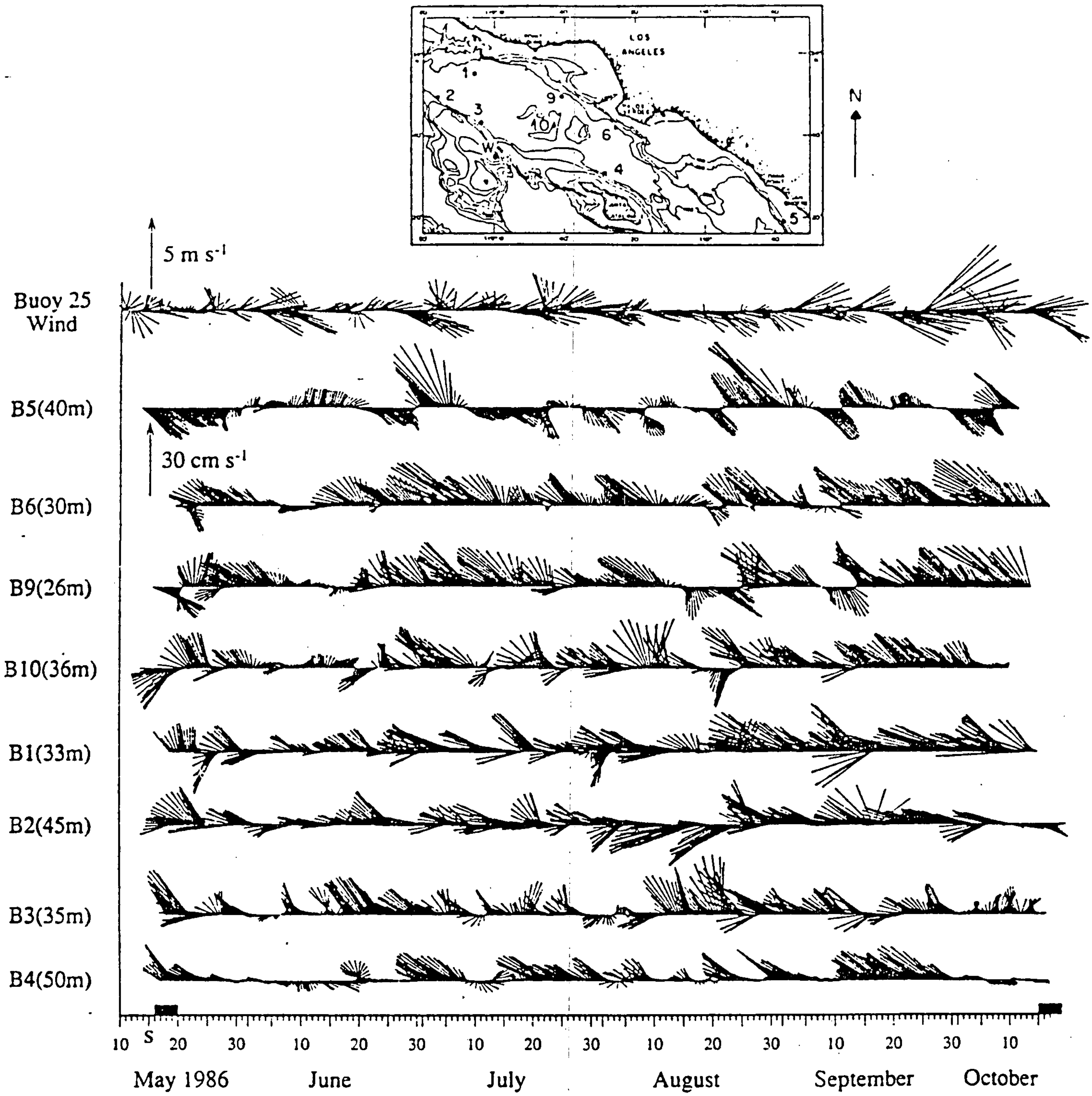



Figure 2-12. Low pass filtered current vectors at the indicated sites and depths during Basin. Note the similarity and magnitudes at B6(30m) and B9(26m). (Hickey, 1992)

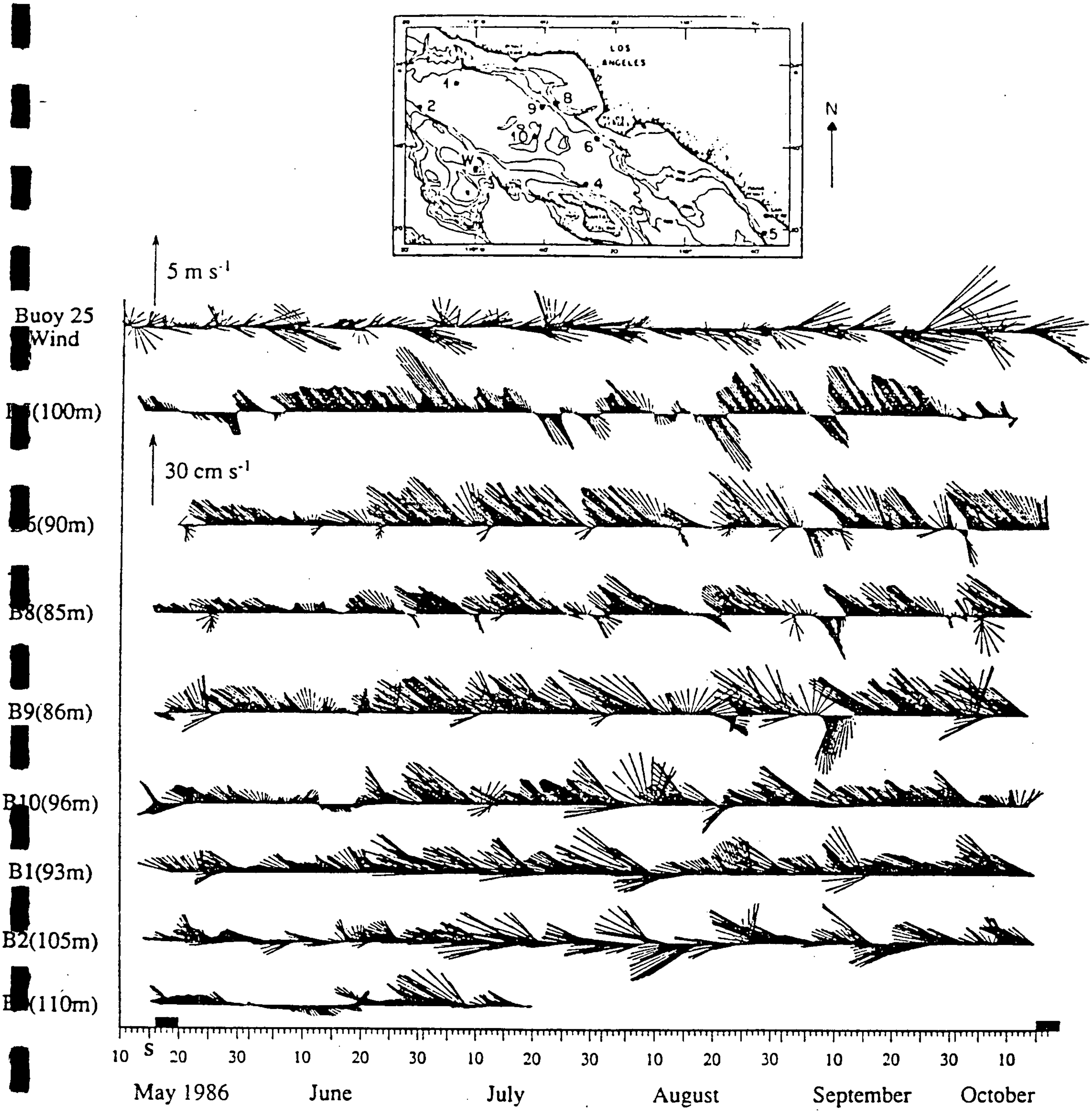



Figure 2-13. Low pass filtered current vectors at the indicated sites and depths. Note that currents at about 90m on B6 and B9 are larger than measured at about 25m. (Hickey, 1992)

## 3.0 REVIEW OF SPECIFIC STUDIES

### 3.1 Summary of Major Oceanographic Programs

Physical oceanographic field programs fall into two categories: scientific programs and engineering programs. Scientific programs are designed to gain information on physical oceanographic processes operating in the study area and their relationship to external forcing by the atmosphere and large scale current systems. The data in these programs is usually subject to dynamical as well as statistical analysis. Engineering programs are usually designed to provide information on the oceanographic regime that will help to determine the dispersal of pollutants and siting of outfalls or dumpsites. The data is often subjected to extensive statistical analysis and may be used in free dispersion models, but this data is rarely analyzed in terms of dynamics or response to external forcing mechanisms.

The SCB is the subject of a number of studies of both types with the engineering studies predominating on the shelf south of Los Angeles. The studies will be listed from north to south, along with a brief description and source of the report, paper or interview. The majority of major academic programs have been summarized in the Mineral Management Service (MMS) report:" Proceedings of Workshop on Southern California Bight Physical Oceanography" (Scripps, 1991). Studies that are not in the vicinity of LA2 or LA5 but may have relevance in that they give information on the oceanographic regimes of the SCB are included for completeness.

#### 3.1.1 Santa Barbara Channel

| | |
|---|---|
| Sponsor: | MMS Investigators/Contractors: Dynalysis and SAIC |
| Field Periods: | 4/83 - 6/83 Pilot Program<br>1/84 - 12/84 Main Program |
| Data Types: | 36 Current Meters on 17 Moorings<br>4 Hydrographic Cruises<br>3 Drifter studies<br>Meteorological and Tide Gauge Data<br>Satellite Imagery |
| Sources: | Gunn et al., (1987)<br>Brink and Muench, (1986)<br>Lagerloef and Bernstein (1988)<br>Lagerloef (1991) |
| Interviews: | Clint Winant (Scripps) |

This MMS study was designed to document the circulation in the Santa Barbara channel and provides significant data for boundary conditions and surface forcing for a prognostic three-dimensional hydrodynamic model. The positions of the moorings and mean currents for two 6-month periods are given in Figure 3-1. Principal results were the documentation of eddies within the channel, the influence of upwelling around Point Conception, and the lack of a strong relationship between winds and local currents.

### 3.1.2 San Pedro and Santa Monica Shelves and Basins

Sponsor: Department of Energy (DOE)

Investigators: B. Hickey (U. of Washington)

Field Periods: CROSS: October 85 - February 86
BASIN: May - October 86
SILL: April - October 87
Transition: February - October 88

Data Types: Each of the above experiments consisted of approximately 10 moorings and 30 current meters. 12 hydrographic cruises were conducted between October 1985 and January 1990 with Lagrangian Drifters in the winter and summer of 1990.

Sources: Hickey (1991); Hickey (1992)

Interviews: Barbara Hickey (UW)

These data are the most extensive shelf and slope measurements made in this region and have documented the occurrence of topographically trapped waves in the basins and shelf currents forced by external currents flowing over the shelf break and upper slope. The latter explains the weakness of the relationship between local longshore winds and currents. Wind forced local upwelling, however, occurs frequently in winter and early spring, but only rarely in summer and fall. Figure 3-2 shows mean upper layer currents for September 1986 from the BASIN experiment. Much of the current meter data from the SILL and Transition experiments have not yet been analyzed. DOE is no-longer funding west coast oceanographic studies (Hickey-personal communication).

### 3.1.3 Whites Point Outfall Studies

Sponsor: Los Angeles County Sanitation Districts (LACSD)

Investigators: LACSD and U.S.C. Ocean Physics Group

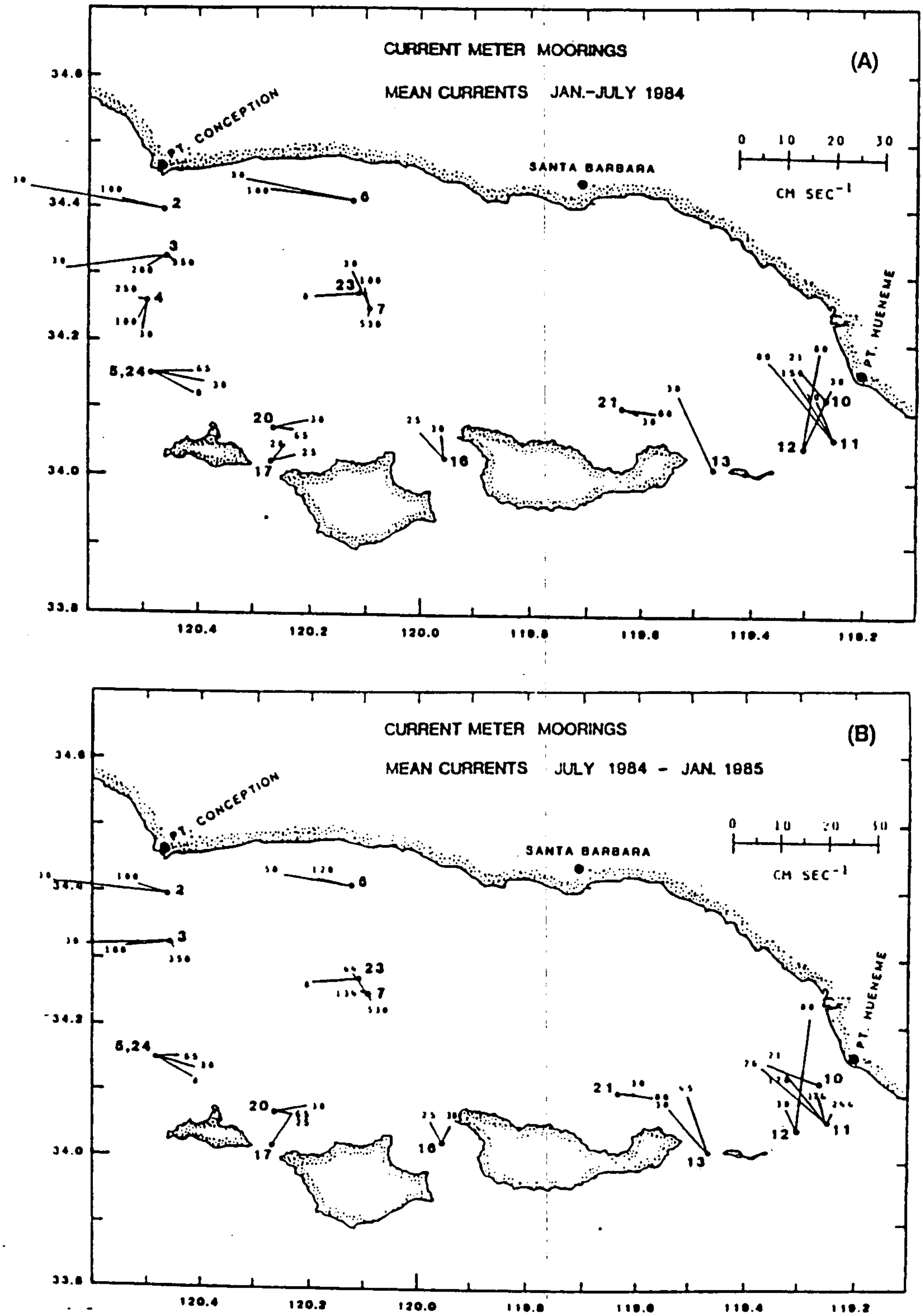



Figure 3-1. Six-month vector averaged currents from the deployment A) January - July 1984 B) July 1984 - January 1985 of the Santa Barbara Channel Study

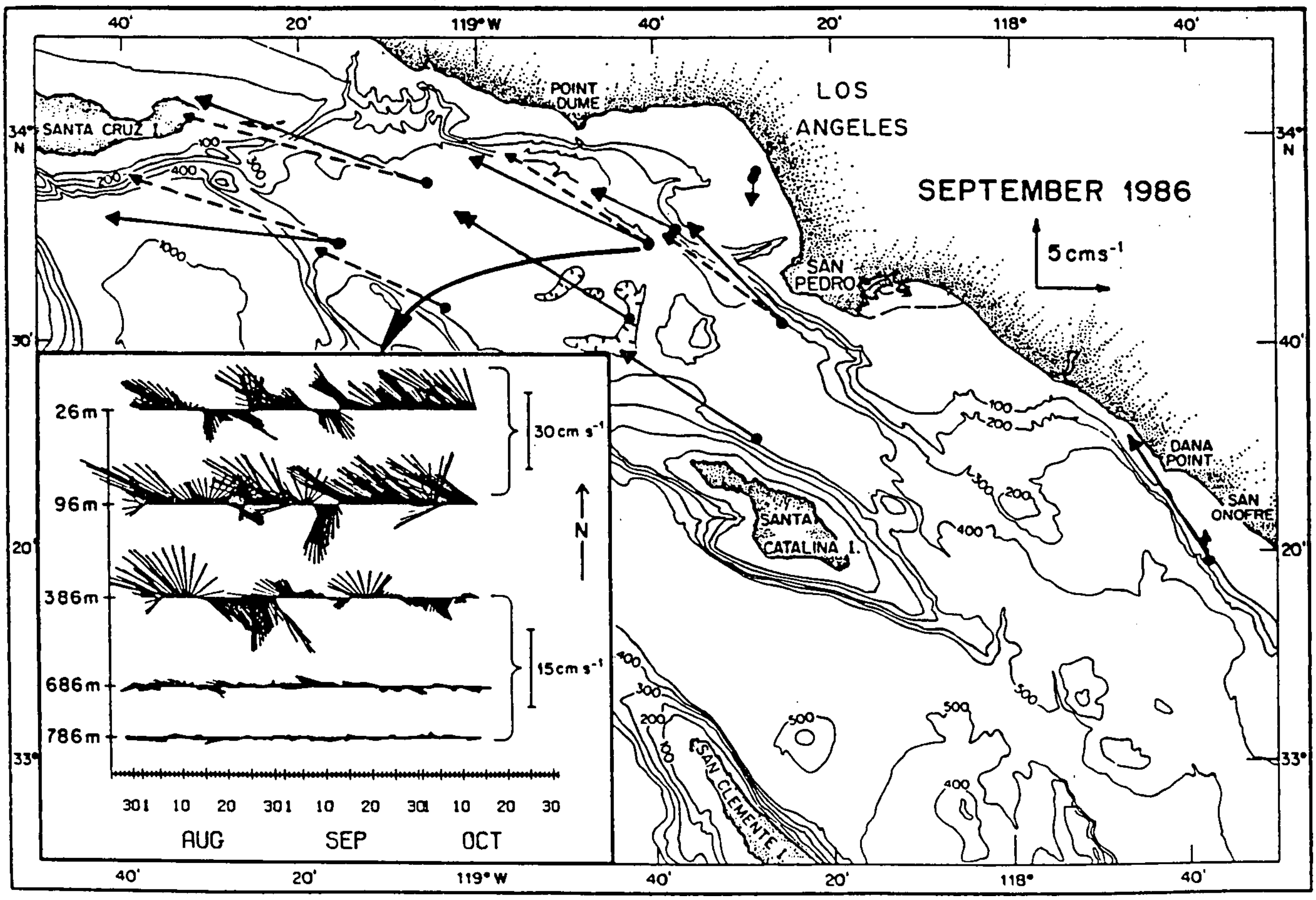



Figure 3-2. Monthly mean flow at 40m (dashed) and 100m (solid) at locations in the Santa Monica and San Pedro basins and at one location in the San Diego Trough (off San Onofre) during September 1986

Field Periods and
Data Types: Monthly water quality surveys at 7 coastal and 21 stations on the Palos Verdes shelf (ongoing since 1981). One current meter mooring in 55m water depth was deployed with 3 or 4 VMCM's for the periods January to May 1985 and July to September 1986.

Sources: LACSD (1990); Siegel et al., (1988) and Washburn et al., (1992).

Interview: Tom Dickey (USC)

Studies conducted by the USC group in 1985 and 1986 concentrated on describing the mixing of the plume from the outfall diffuser using towed instruments (Figure 3-3). The currents showed mean upcoast flows for both deployment periods with larger magnitudes at depth. Figure 3-3 shows a transition from downcoast flows to upcoast flows in August 1986. The hydrographic and water quality surveys have documented upwelling events on the Palos Verdes shelf.

### 3.1.4 Terminal Island Treatment Plant Oceanographic Studies

Sponsor: City of Los Angeles Wastewater Program, Management Division

Contractor: Engineering Science

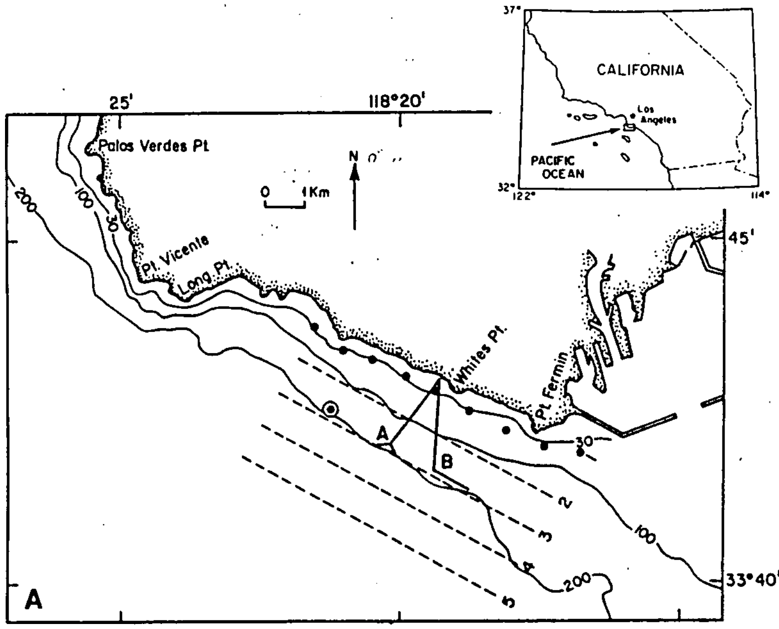
Field Periods: December 1989 - August 1990

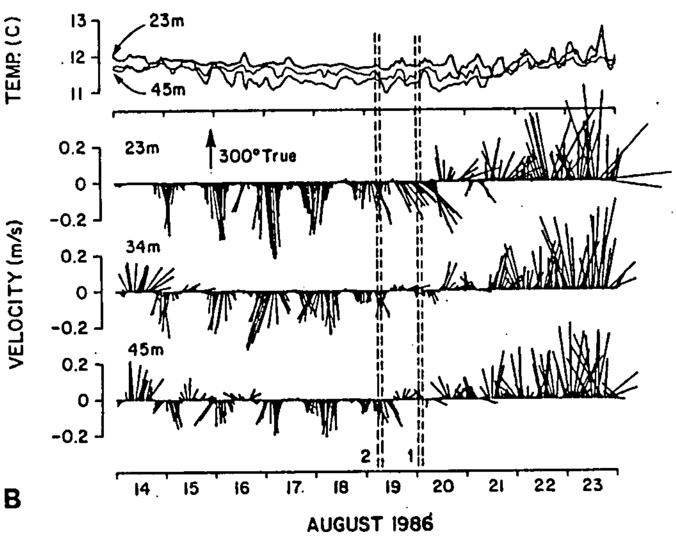
Data Types: 9 current meters on 5 moorings Monthly Hydrographic/Water quality surveys (21 stations)

Sources: Engineering Science (1991)

Interview: Paul Amberg (ESI)

Mean currents on the San Pedro shelf were down coast during the winter and spring periods and upcoast during the summer (Figure 3-4). The flows over the San Pedro shelf were often quite different than on the narrow Palos Verdes shelf (CM-5). Currents were more energetic in spring and summer than in the winter with the shelf break showing larger fluctuations than the inner or midshelf. CM-3 on the San Pedro shelf seems to be influenced by the complex topography of the head of the San Pedro canyon.




B

Figure 3-3. A) Study area offshore of the Palos Verdes Peninsula on the Southern California coast

9206.013/8.023



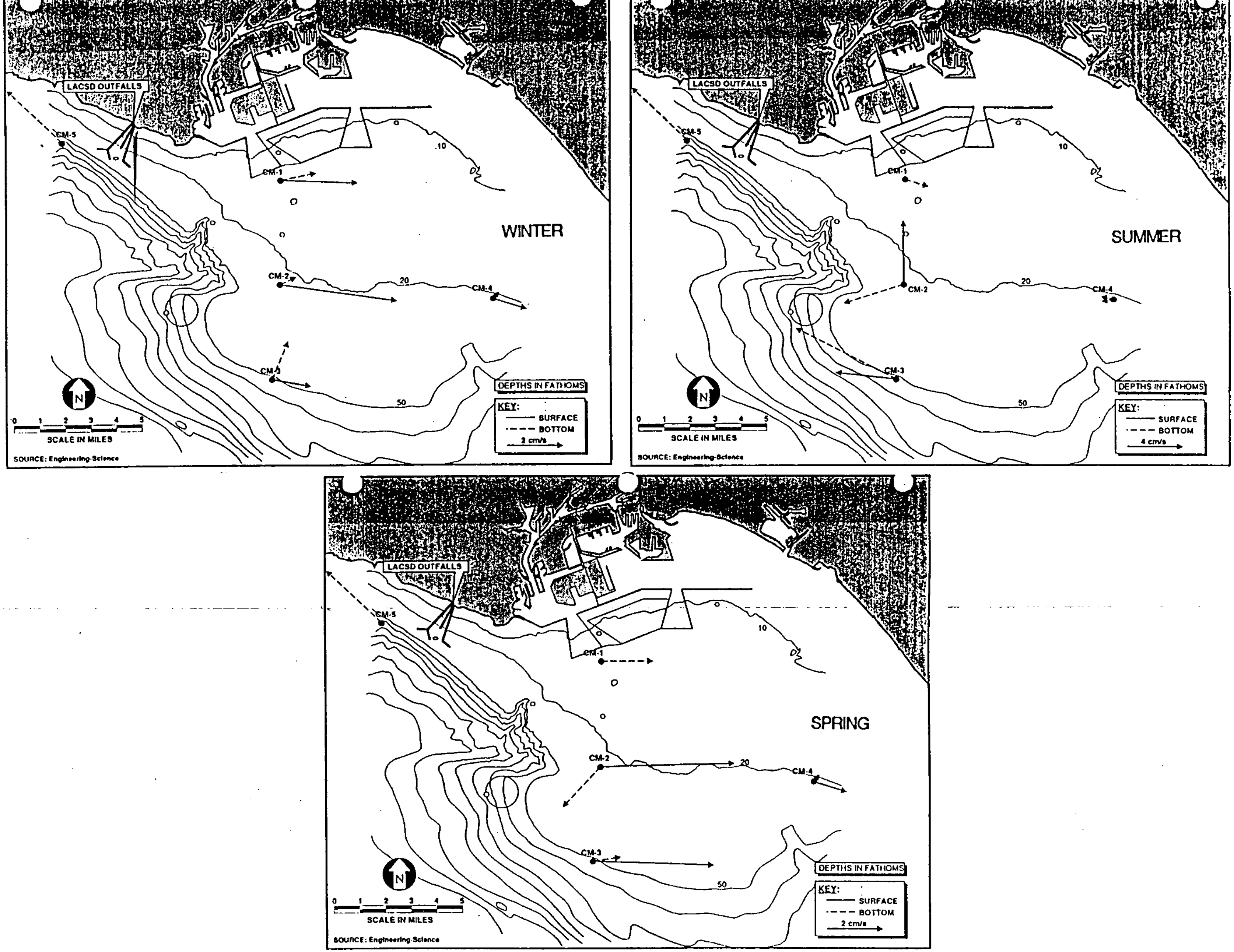



Figure 3-4. Mean currents for the winter, spring and summer periods of the Terminal Island Treatment Plan Oceanographic data collection program

### 3.1.5 Orange County Outfall Studies

| | |
|---|---|
| Sponsor: | County Sanitation Districts of Orange County (CSDOC) |
| Contractor: | MEC |
| Field Periods: | June 86 to June 89 |
| Data Types: | Typically about 12 current meters on 8 moorings for each year of the program. One mooring was used for a thermistor string. Monthly hydrographic and water quality surveys. |
| Sources: | CSDOC (1989) |
| Interviews: | Paul Amberg (ESI) |

These studies monitored the oceanographic regime in the vicinity of the District's outfall between Huntington and Newport Beaches. The moorings were deployed along the outfall transect as well as the head of the Newport Canyon and on the San Pedro shelf. Figure 3-5 shows the mooring positions and seasonal mean currents for 1988. Summer current patterns show southward flow near the surface and poleward flow in the deeper layers. Flows become poleward in the fall over the outer shelf. The strongest surface equatorward flows occur in spring. Stratification over the shelf varies from weak in winter to strong in summer. Currents at the head of the Newport canyon were generally very weak in all seasons. Current fluctuations were quite coherent at all moorings and showed little of the characteristics of wind-forced flows. The strongest were again found on the outer shelf.

### 3.1.6 San Onofre Nuclear Generating Station (SONGS)

| | |
|---|---|
| Sponsor: | Marine Review Committee |
| Contractor: | ECO Systems Management Association, Inc. |
| Field Period: | February 1977 to December 1986 |
| Data Types: | Various Current Meter Arrays, Temperature and Salinity Measurements |
| Sources: | Rietzel et al., (1988); Winant (1983); Lentz (1986) |
| Interview: | Clint Winant (Scripps) |

The Marine Review Committee has sponsored various experiments in the vicinity of the San Onofre power station outfall that have resulted in many years of noncontinuous data. Daily averaged currents for data collection periods between 1977 and 1986 are given in Figure 3-6. Winant (1983) and Lentz (1986) have reported on the coherence of longshore currents along the 30m isobath at midshelf for the summer and

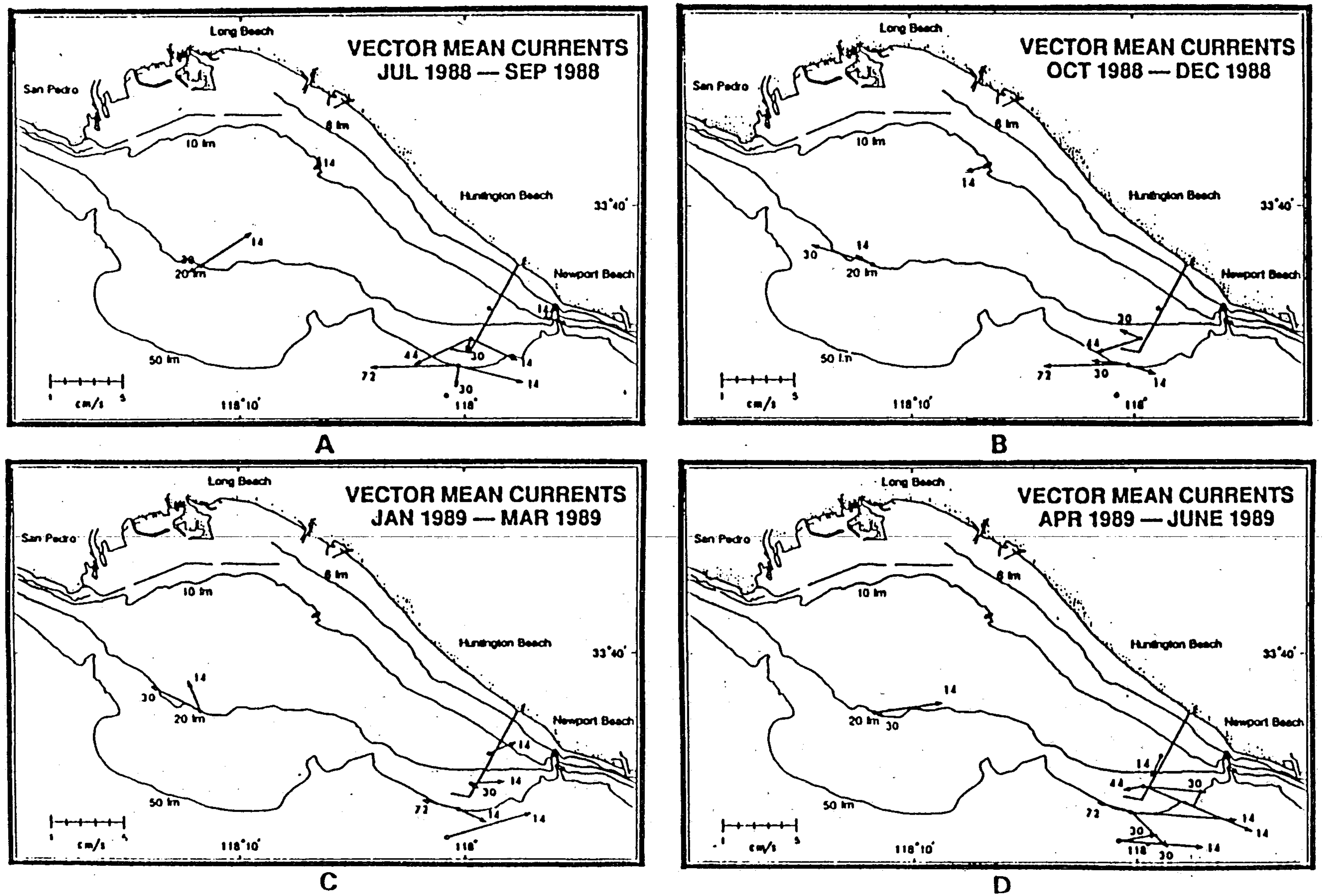



Figure 3-5. Seasonal mean currents for the period July 1988 to June 1989 for the County Sanitation District of Orange County outfall study

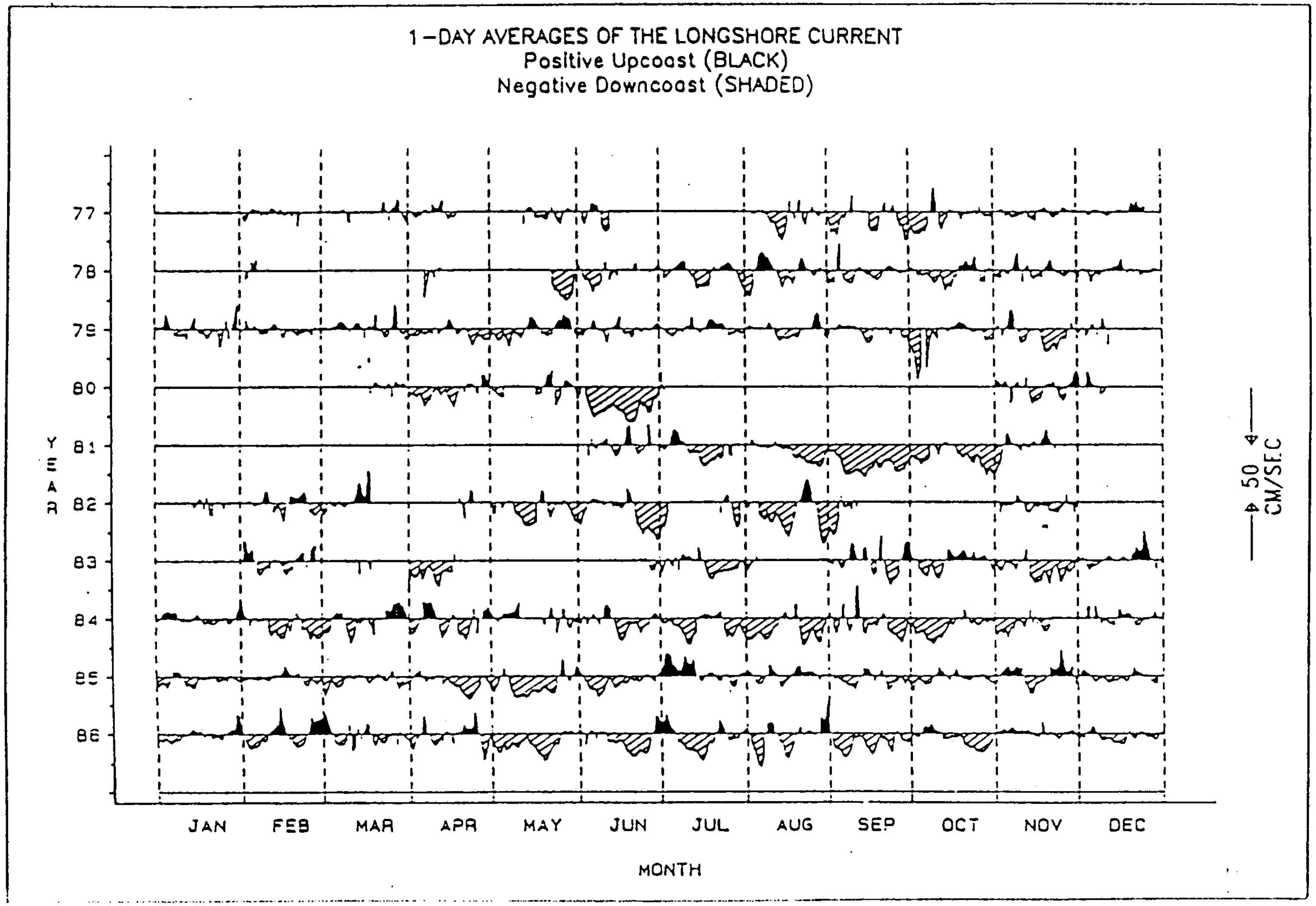



Figure 3-6. Ten-year history of daily mean longshore current from the SONGS studies

winter/spring, respectively. Low frequency longshore currents with periods of a few days to a few weeks are coherent at alongshelf scales of between 25 and greater than 60km in the summer and winter, respectively. Cross-shelf current components and tidal frequency motions have only short longshore length scales of between 2 and 10 km.

### 3.1.7 Del Mar Current Measurements

Sponsor: National Science Foundation (NSF)

Investigator: C.D. Winant

Field Periods: May 16 - June 27, 1978
July 27 - September 11, 1978
October 21 - December 4, 1978
December 21 - March 26, 1979

Data Types: Cross shelf array of 3 moorings and up to 16 current meters.

Sources: Winant and Bratkovich (1981), Bratkovich (1985) Lentz and Winant (1986).

Interview: Clint Winant (Scripps)

A cross shelf array was deployed off Del Mar (Figure 3-7). Mean currents over the one year period were southward. Fluctuations in winter for a few days to a few weeks may be explained as a combination of local wind forcing and coastal trapped waves. Strong stratification in summer and forcing by offshore eddies complicate the responses in summer. Internal tidal motions were also noted in the strongly stratified summer season.

### 3.1.8 Point Loma Outfall Extension Study

Sponsor: City of San Diego

Contractor: Engineering Science

Field Periods: February 1990 I- April 1991

Data Types: 7 moorings with 19 current meters and 6 thermistor strings. Monthly hydrographic and water quality cruises at 19 stations.

Sources: Engineering Science (1991)

Interview: Paul Amberg (ESI)

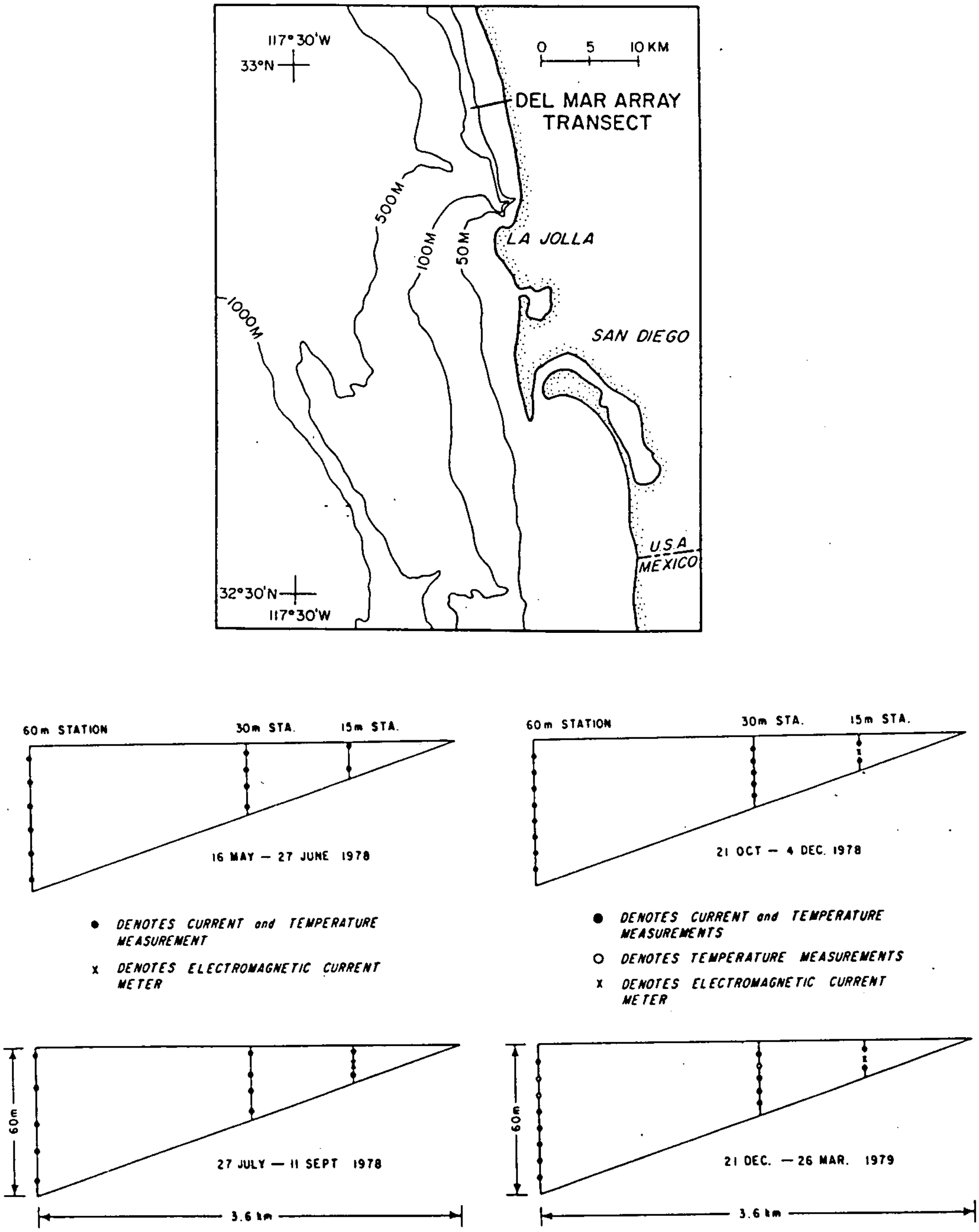



Figure 3-7. Instrument configurations and deployment intervals

Figure 3-8 shows the positions of the current meter moorings and water quality stations around the Point Loma outfall. Upcoast flows tend to dominate in the winter and spring periods with stronger flows in deeper water. There were also substantial onshore flows at mid or bottom depths, which were sometimes stronger than the alongshore flows. This data does not appear to have been analyzed for forcing mechanisms.

### 3.1.9 Tijuana Oceanographic Engineering Study (TOES)

| | |
|---|---|
| Sponsor: | City of San Diego |
| Contractor: | Engineering Science |
| Field Periods: | Phases I and II, May 1986 - August 1987. (Up to 10 current meter moorings)<br>Phase III December 1987 - December 1988 (2 current meter moorings) |
| Data Types: | 10 Current Meters and monthly hydrographic/water quality surveys. Drifters and Satellite Imagery. |
| Source: | Engineering Science (1988) |
| Interview: | Paul Amberg, T. Hendricks (SCCWRP) |

This engineering study for the siting of a sewage outfall near the international boundary has produced an extensive data set. Phases I and II were the most comprehensive parts of the study and the mooring and station positions are given in Figure 3-9. In Phase III, two current meter moorings were deployed near C4 and C2 (Figure 3-9) and a sparse grid of 12 water quality stations was occupied between the border and Point Loma. The current meter data identified an eddy south of Point Loma that rotated clockwise or anticlockwise, depending on the prevailing direction of the middle and outer shelf flow. Downcoast flows predominated during Phases I and II. This current data was used to construct a numerical/statistical model of the predominant flow patterns observed during the study to allow an evaluation of dispersion from the outfall to be made.

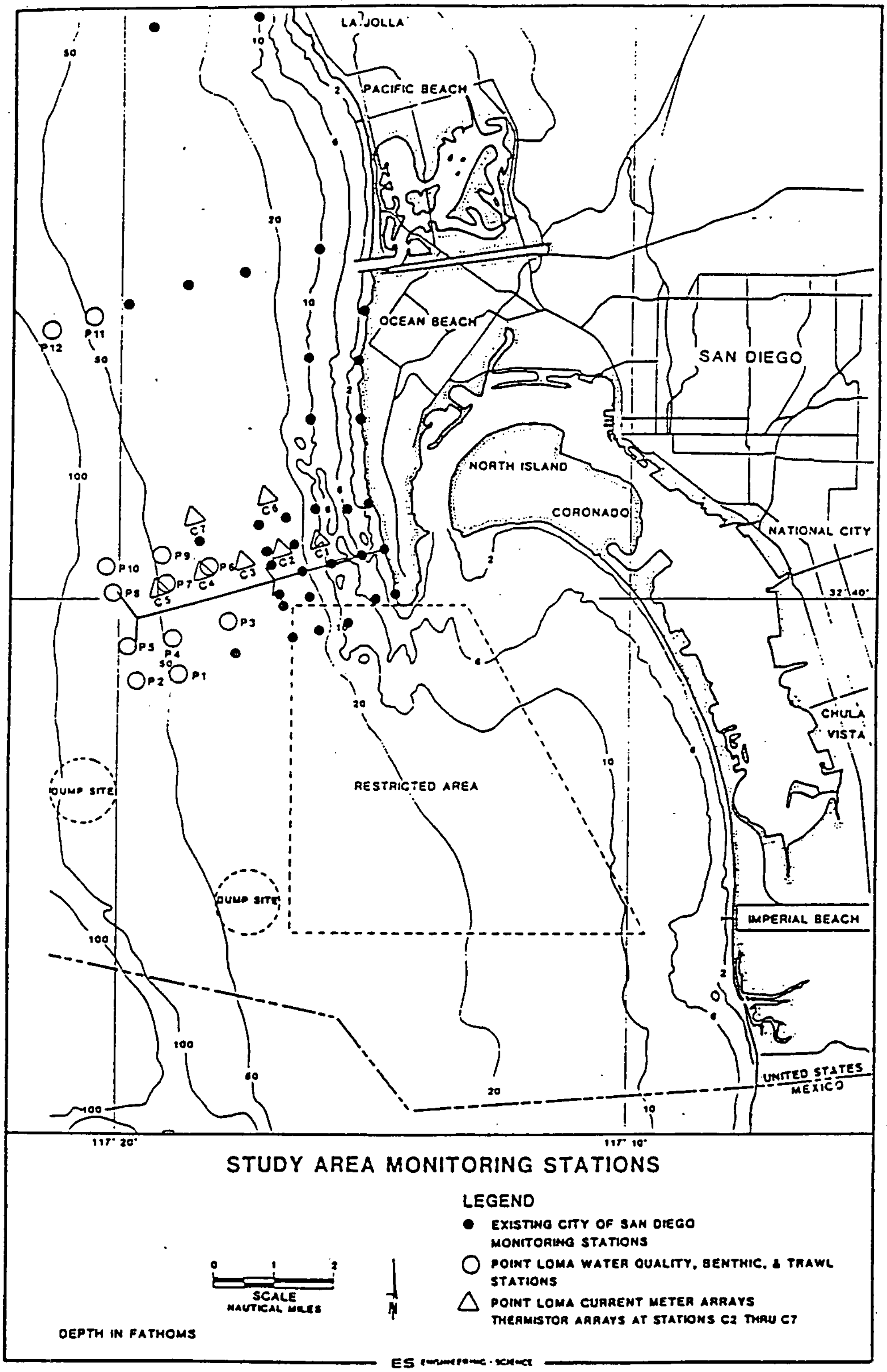



Figure 3-8. Point Loma outfall study region showing the positions of the monitoring stations.

Table 3-1. SUMMARY OF INTERVIEWS

| Name | Affiliation | Date | Notes |
| --- | --- | --- | --- |
| Tom Dickey | USC | 10 March, 92 | References Provided |
| Burton H. Jones | USC | 10 March, 92 | w/Dickey |
| Herman Karl | USGS | 16 April, 92 | References Provided |
| Donn Gorsline | USC | Feb, 92 | References Provided |
| Dorothy Soule | USC | 10 March, 92 | Limited Information |
| Jan Stull | LA County Sanitation District 16 | 16 March, 92 | References Provided |
| Alex Steele | LA County Sanitation District 16 | 16 March, 92 | Reference Provided |
| Terry Hendricks | SCCWRP | 7 May, 92 | References Provided |
| Bruce Thompson | SCCWRP | ----------- | References Provided w/Hendricks |
| Steve Lentz | Woods Hole | 8 May, 92 | References Provided |
| Clint Winant | Scripps | 27 Feb, 92 | References Provided |
| Barbara Hickey | U of W | 13 May, 92 | References Provided |
| Dan Muslin | Naval Facility Eng. Cmmd. | 21 May, 92 | Limited Information |
| Greg McBain | ESI | ---------- | Referred to Amberg |
| Paul Amberg | ESI | 27 Feb, 92 | References Provided |
| William Muellenhoff | Battelle Labs | May, 92 | Limited Information |

## 3.2 Application of Studies to the LA-2 and LA-5 Sites

The overview of regional studies based upon the literature reviews and interviews shows a number of current measurements that are directly relevant to the LA-2 and LA-5 disposal sites. No measurements have been made directly at the two sites. However, moorings have been deployed in similar water depths on the outer shelf nearby. Thus, the current profiles measured at these sites will provide direct comparisons with data from the LA-2 and LA-5 monitoring programs.

The LA-2 site off Los Angeles has the most nearby data. On the shelf, there are current meter moorings from Palos Verdes (Figure 3-3), and Terminal Island (Figure 3-4, mooring CM-2 and CM-3) and the Orange County studies (Figure 3-5). On the slope off Palos Verdes, Hickey (1992) has deployed a mooring on about the 600m isobath (Figure 3-2). Comparing the mean currents in these figures shows both upcoast and downcoast flows depending on season and instrument depth. Near surface flows on the shelf have a tendency to be downcoast in winter and spring and upcoast in summer. Deeper currents over the slope have greater tendency to be poleward at most times of the year. However, there are inconsistencies between experiments which are attributed to interannual variability of the Southern California Eddy, the California Undercurrent and the seasonal wind regimes. Hickey (1992) has pointed out that the current over the shelf break in regions such as LA-2 have a substantial component that is forced by offshore flows over the slope. Figure 3-3(B) gives a good example of how predominantly downcoast flows over the Palos Verdes shelf break change to upcoast flows as warmer water from the California Undercurrent moves in over the outer shelf. There have also been sediment transport studies using bottom mounted tripods (GEOPROBE) on the San Pedro shelf which have documented the importance of swells in resuspending silts and fine sands on the shelf (Drake et al., 1985). There appears to be a continual flux of fine grain sediments from the shelf onto the steep continental slope (Karl, et al., 1983).

The LA-5 site off Point Loma has two directly relevant studies: the Point Loma outfall extension (Figure 3-8; mooring C5 and C7) and TOES (Figure 3-9; moorings C5 and C4). Both these data sets do seem to have been extensively analyzed and therefore comparisons with LA-5 monitoring data is likely to be in terms of basis statistics. The Del Mar current data (Figure 3-7) and some of the SONGS arrays (Winant 1983) have been subject to comprehensive process-based analyses and thus can give information on the type of anticipated shelf-edge currents at LA-5. Longshore coherence scales in this region are greater than 50 km in winter (Lenz, 1986); however, the similarity of flows at LA-5 and Del Mar may be affected by the topography of the La Jolla Canyon and coastline curvature south of Point Loma (Figure 3-7).

Lagerloef, G.S.E., 1991. MMS Studies in the Santa Barbara Channel. In Southern California Bight Physical Oceanography. U.S Department of Interior, MMS, Pacific OCS Office, OCS Study MMS 91-0033. pp 69-90.

Lagerloef, G.S.E., and R.L. Bernstein. 1988. Empirical orthogonal function analysis of advanced very high resolution radiometer surface temperature patterns in Santa Barbara Channel. J. Geophys. Res. 93:6863-6873.

Lentz, S.J. 1984. Subinertial motions on the Southern California Continental Shelf. Ph.D. thesis. Univ. California San Diego, CA 145 pp.

Lentz, S.J. 1986. The spatial coherence of motions in the ocean offshore of the San Onofre nuclear generating station during the winter. Final report prepared for the Marine Review Committee, Inc. 40 p.

Lentz, S.J., and C.D. Winant. 1986. Subinertial currents on the Southern California Shelf. J. Phys. Oceanogr. 16:1737-1750.

Los Angeles County Sanitation Districts, 1991 Palos Verdes Ocean Monitoring Annual Report, 1990 Chapter 2 - Physical Oceanography. Prepared for Los Angeles Regional Water Quality Control Board. 75 pp.

Lynn, R.S. and J.J. Simpson (1990). The flow of the undercurrent over the continental borderland off southern California. Journal of Geophysical Research, 95 (C8): 12,9959-13,009.

Lynn, R.J., and J.J. Simpson. 1987. The California current system: the seasonal variability of its physical characteristics. J. Geophys. Res. 92(C12): 12947-12966.

Mass, C.S. (1989). The origin of the Catalina Eddy. Monthly Weather Review 89 (11): 2,406-2,436.

Orange County (Calif.), County Sanitation Districts, (CSDOC) 1989. Annual Report 1989. Marine monitoring. Volume 3A of 3 and 3B of 3. Fountain Valley, CA. County Sanitation Districts of Orange County.

Poulain, P.M., and P.P. Niiler. 1989. Statistical analysis of the surface circulation in the California current system using satellite-tracked drifters. J. Phys. Oceanog. 19(10):1588-1603.

Reitzel, J., H. Elwany, K. Zabloudil, and M.R. Erdman 1988. The natural environmental near San Onofre: Physical/chemical oceanography program at SONGS. Draft Final Report 1987. Vol. 11-1. ECOSystems Management Assoc., Inc. Encinitas, CA.

Scripps, 1991. Southern California Bight Physical Oceanography. U.S. Department of Interior, MMS, Pacific OCS Office. OCS Study MMS 91-0033, 157 pp.

Siegel, D.A., B.H. Jones, T.D. Dickey, I. Haydock, and A. Bratkovich, 1988. Effects of Nearshore Upwelling on Coliform Dispersion near the Whites Point Outfall. In Coastal Marine Environment: Oceanic Process in Marine Pollution (edit D.A. Wolfe and J.P. O'Connor) Krieger Publ., Malebar, Florida.

Shepard, F.P., Marshall N.F., McLaughlin, P.A., and Sullivan G. G., 1979. Currents in submarine canyons and other sea valleys: Am. Assoc. Petroleum Geologists, Studies in Geology No. 8, 173 p.

Simpson, J.J., C.J. Koblinsky, L.R. Haury, and T.D. Dickey. 1984. An offshore eddy in the California Current system, Prog. Oceanogr. 13:1-111.

Simpson, J.J. and R.J. Lynn, 1990. A Mesoscale Eddy Dipole in the Offshore California Current J. Geophys. Res., 95, 13,009-13,002.

Sommers, W.T. 1987. LFM forecast variables related to Santa Ana wind occurrences. Mon. Wea.-Rev. 106:1307-1316.

Washburn, L., B.H. Jones, A. Bratkovich, T.D. Dickey and M-S Chen, 1992. Mixing, Dispersion and Resuspension in Vicinity of Ocean Wastewater Plume J. Hydr. Eng. (ASCE) 118, 38-58.

Winant, C.D. 1980. Downwelling over the Southern California Shelf. J. Phys. Oceanogr. 10(5):791-799.

Winant, C.D. 1983. Longshore coherence of currents on the Southern California Shelf during the summer. J. Phys. Oceanogr. 13(1):54-64.

Winant, C.D., and A.W. Bratkovich. 1981. Temperature and currents on the Southern California Shelf: A description of the variability. J. Phys. Oceanogr. 11(1):71-86.